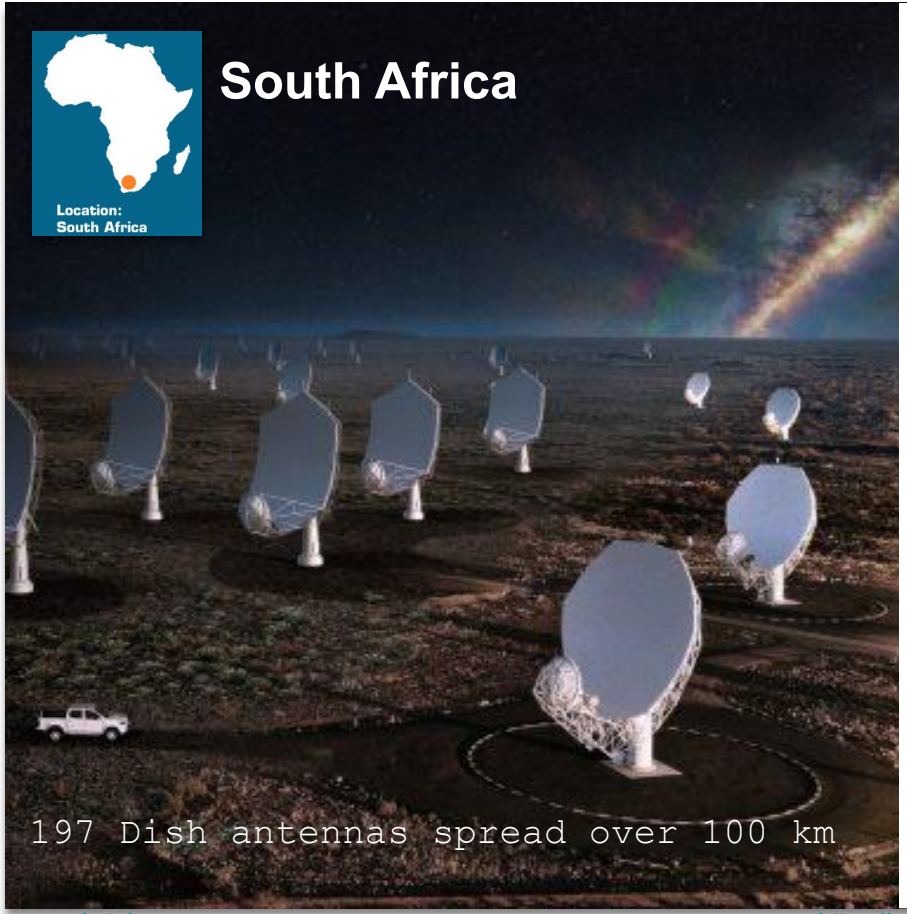
Fast Transient Search with the SKA

FTSky: A program in the field of Fast Radio Transients

Prabu Thiagaraj
RRI, Bengaluru, India

ICTS - Thursday, 16 October 2025

Square Kilometre Array (SKA) is the most sensitive Radio Telescope being deployed in the most radio-quiet parts of the world



www.skatelescope.org https://population.com.au/lga/56160 https://en.wikipedia.org/wiki/Bangalore_Urban_district

Square Kilometre Array - a background

Pre 1990 ET Telescope

- Proposed by Barney Oliver and John Billingham
- Detecting extraterrestrial intelligent life
- 1000 x 100 m dishes working at cm wavelengths

1986-1989 Radio Schmidt telescope

- Proposed by Canadians
- Emphasis on surveys
- Create an all sky survey telescope
- Wide field of view
- Large numbers of small dishes
- Peter Dewdney's 100 x 12m antennas

Ekers, 2012

Square Kilometre Array - a background

1988 and 1990 Dutch Extragalactic HI telescope

- Proposed by Robert Braun, Ger de Brujn and Jan Noordam
- Aimed **to detect HI at high redshift.**
- Build with enough collecting area

1991 International Radio Astronomy Telescope (ITRA)

- Proposed by Govind Swarup in India
- a next generation cm radio telescope based on GMRT (being built)
- Included 160 x 75m dishes,
- Centrally concentrated
- Baselines up to 200km

Ekers, 2012

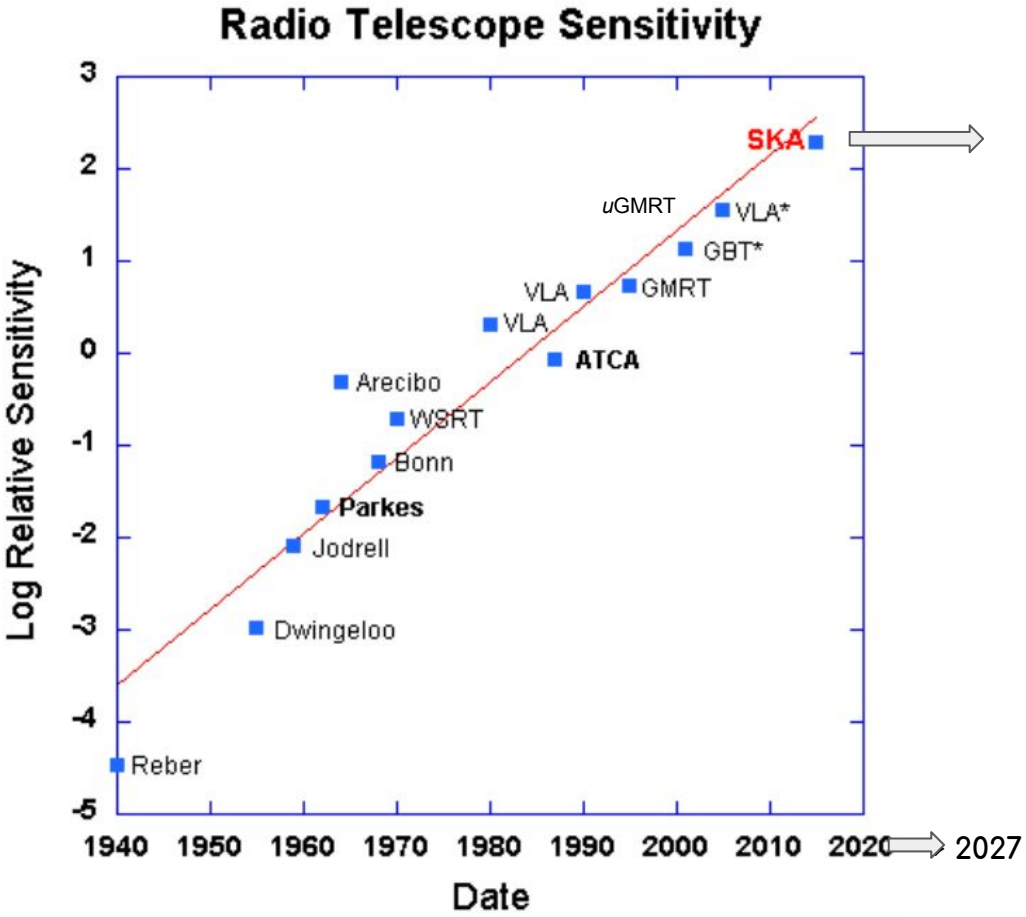
Square Kilometre Array
A Technology Challenge

1. Aperture arrays at lower frequencies
2. Dish arrays at higher frequencies
3. Transition frequency to be determined by technology development
4. Revolutionary break with current radio telescope design
5. Use of Large scale Integration of Transistors
6. Use of rapidly evolving Digital Technology
7. Use of novel signal processing algorithms
8. Benefit using from COTS devices, where possible
9. Participating countries design & build prototypes
10. Key technologies will be determined later
11. Avoid duplicate efforts
12. Achieve affordable cost

Ekers, 2012

Since the first discovery of extraterrestrial radio emission in 1940

- Relative continuum point source sensitivity of radio telescopes
- Exponential increase in sensitivity of 10^5 since 1940
- Doubling every three years
- Important discoveries in astronomy resulted from these technical innovations.

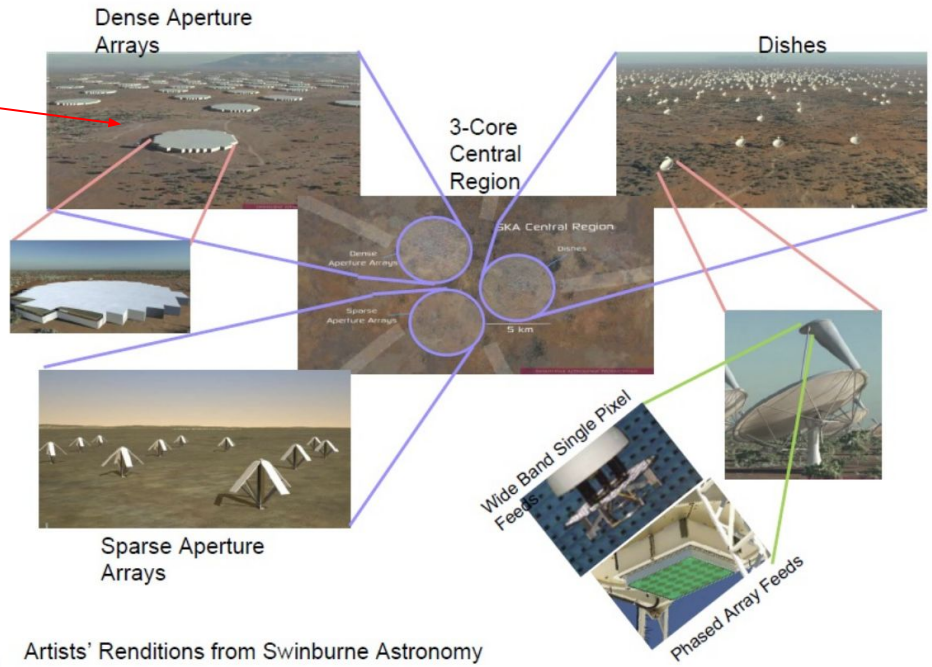


Exponential growth in science

Ekers, 2012

Conceptual design

Closely spaced simple broad-band antennas
No grating lobes: lower half of the band.
~400MHz to 1.4GHz. The FOV is ~200deg 2



Artists' Renditions from Swinburne Astronomy

https://www.researchgate.net/publication/273401912

For low frequency between 500 - 1000 MHz
Variety of choices considered

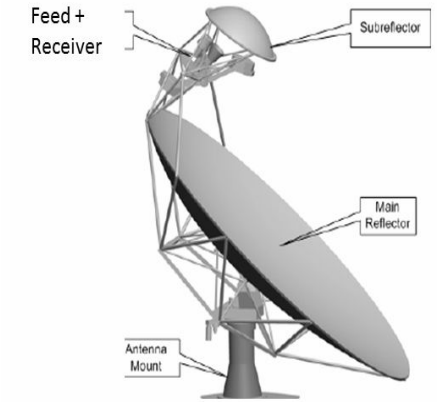
Where as for the higher frequencies > 1 GHz choice of Dish was inevitable

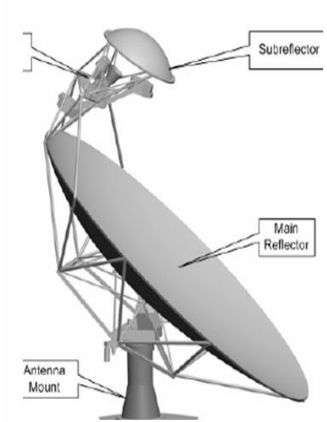
Aperture synthesis by using small dishes

Interferometric techniques
Phased arrays

Dish challenges:

- Multi pixels in feed
- Dish dimensions





SKA Mid South Africa
about 200 Dishes

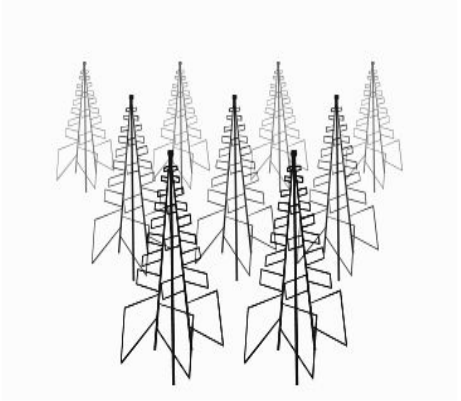
Challenges

Power

Size

Performance

Future Technology



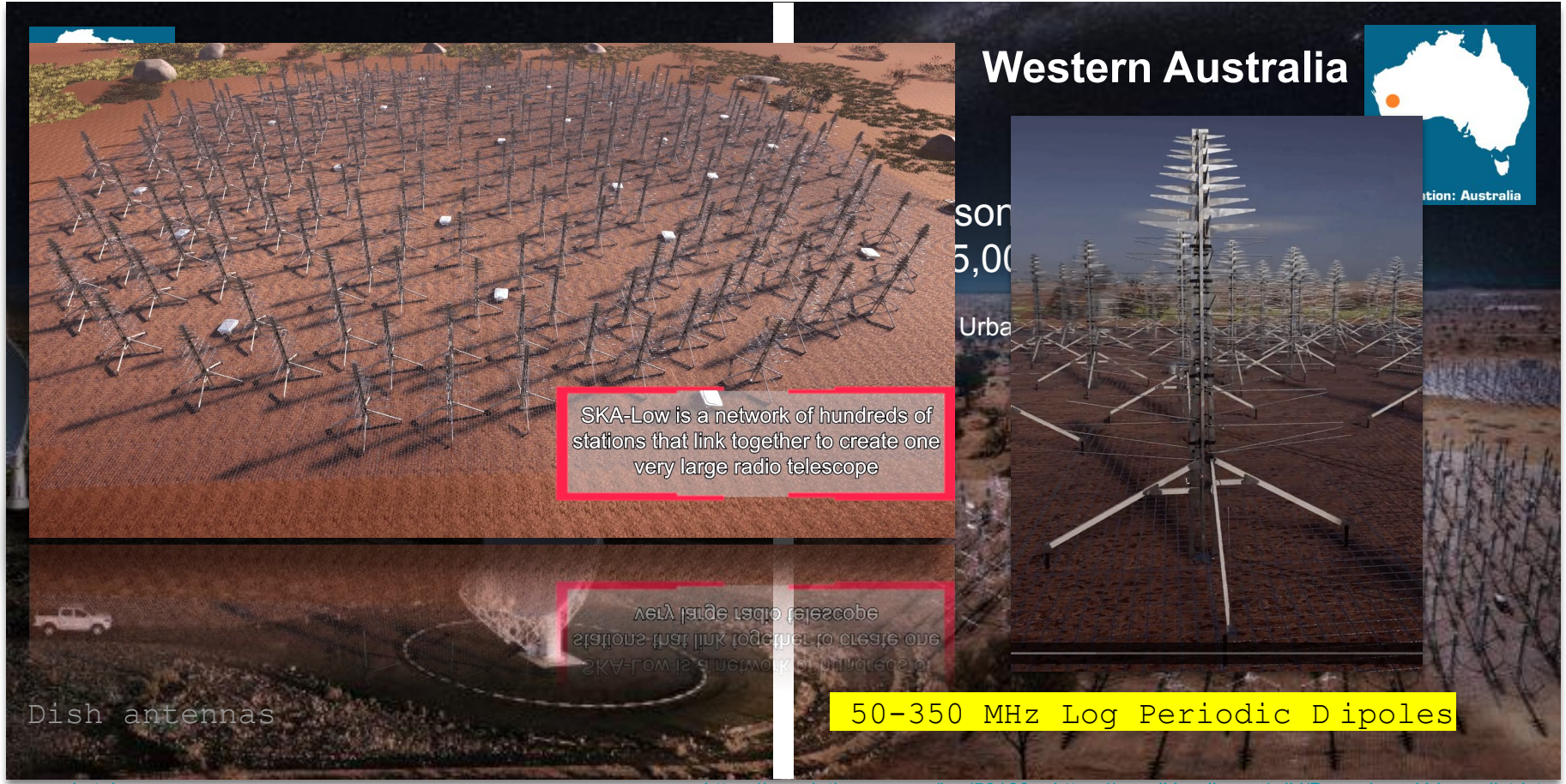
SKA Low Western Australia
about 1,32,000 dipole antennas

SKA1 Mid antennas are coming up

Synchronisation dance with MeerKAT

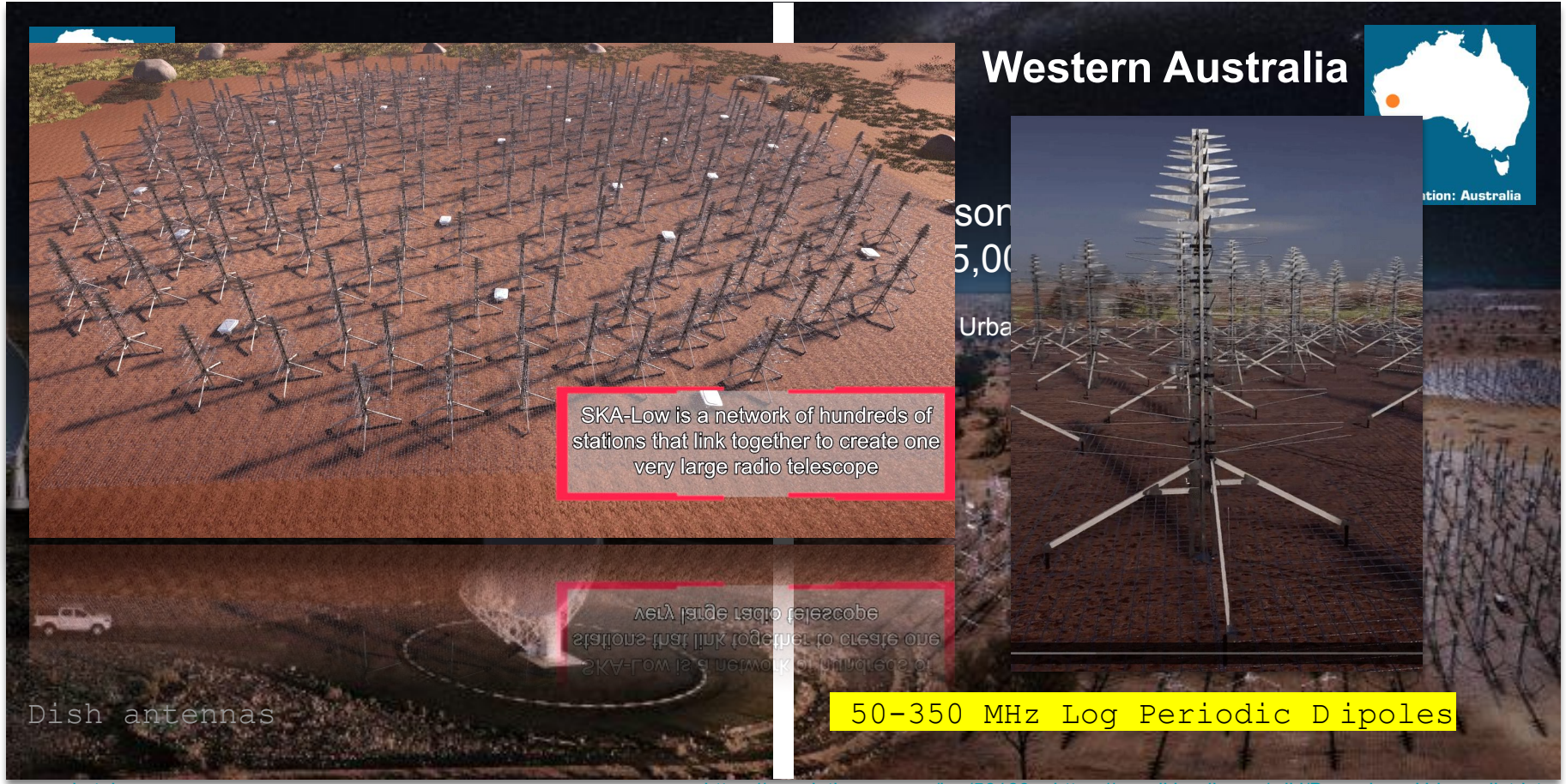
In August 2024, the first SKA-Mid dish tested its synchronisation with the MeerKAT telescope. This is not only a spectacular sight but also an important feature for when the dishes will eventually be part of the same array. - https://www.skao.int/en/explore/construction-journey

Square Kilometre Array (SKA) is the most sensitive Radio Telescope being deployed in the most radio-quiet parts of the world



www.skatelescope.org https://population.com.au/lga/56160 https://en.wikipedia.org/wiki/Bangalore_Urban_district

Square Kilometre Array (SKA) is the most sensitive Radio Telescope being deployed in the most radio-quiet parts of the world



www.skatelescope.org https://population.com.au/lga/56160 https://en.wikipedia.org/wiki/Bangalore_Urban_district

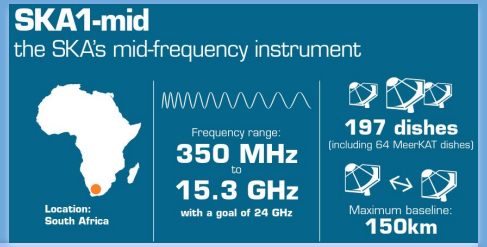
Pulsar Observations with these Telescopes

Outstanding demands from Science Cases

Masses of NSs play a vital role in a number of aspects pertaining to their structure, formation and evolution
⇒ Pulsar Timing

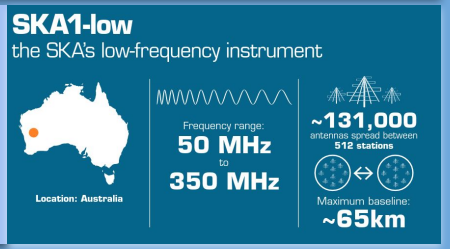
SKA1 is expected to increase the number of known pulsar binaries by five(!), which should therefore grow the NS mass sample size by a similar factor.

Justified for relativistic NS–NS binaries since their mass measurements rely on radio timing only.



With SKA1-MID, it will be possible to measure positions accurate to several milli-arcseconds in a single observation for all bright pulsars.

With SKA1-Low, it will be possible to measure the DMs to an unprecedented accuracies



Questions seeking larger statistical samples

Science goals of Square Kilometre Array
Most sensitive radio telescope

Cosmology

Epoch of Reionization and the Dark Ages

Radio Transients

Cosmic Magnetism

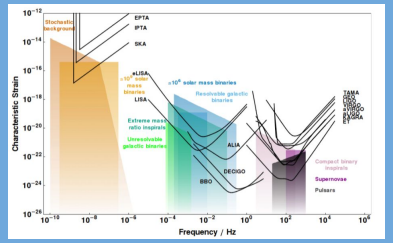
Science cases

Fundamental Physics with Pulsars

Continuum Surveys

HI and Galaxy Evolution

Astrobiology/Cradle of Life



GW: Will enhance PTA Science

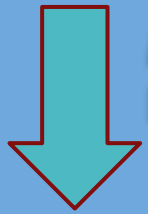
Searching Pulsars with SKA

Means moving the Offline Processing to a Real Time Processing

Computing Challenge

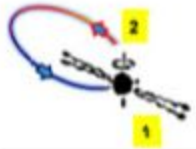
Moving Offline Processing to Real Time Processing

57 Years of
Pulsar Search Techniques



Matured over Five decades

Pulsar Search
can be attempted in real-time
However, it is a Challenge for SKA due to the large data and computing that need to be handled



1

SKA1-Low
500 beams

SKA1-Mid
1500 beams

2

Search in

1. DM Space
2. Pulse width
3. Pulse Period
4. Binary Orbit
5. Deal with RFI

A common architecture SKA1-Low & Mid

3

Dedispersion:	~	2 Tera OPS
Long FFT	~	1 Tera OPS
Acceleration trials:	~	10 Peta OPS
Folding/Optimisation:	~	140Tera OPS

SKA Telescopes

Challenges

Performance
Size
Power

4

Future Technology 5

Pulsar Search

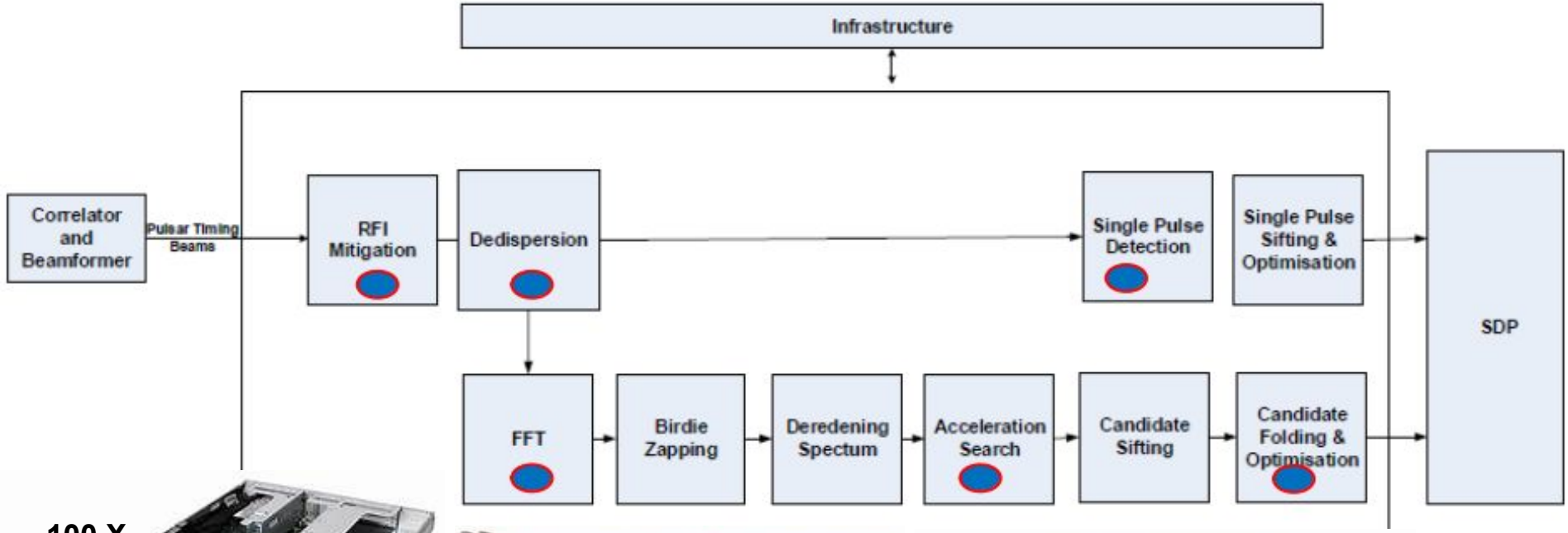
~10 Peta-OPS

~60 Peta-bytes/day

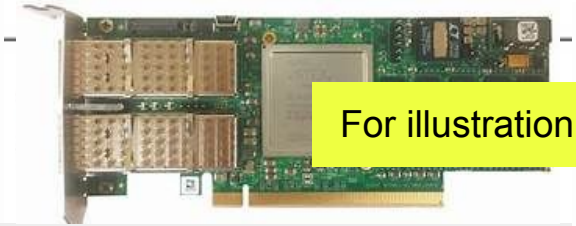
⇒ 2 TB X 30,000 Disks
⇒ 16 TB X 2000 Disks

Pulsar search with SKA requires enormous real-time computing

Pulsar search pipeline for SKA & Current Status



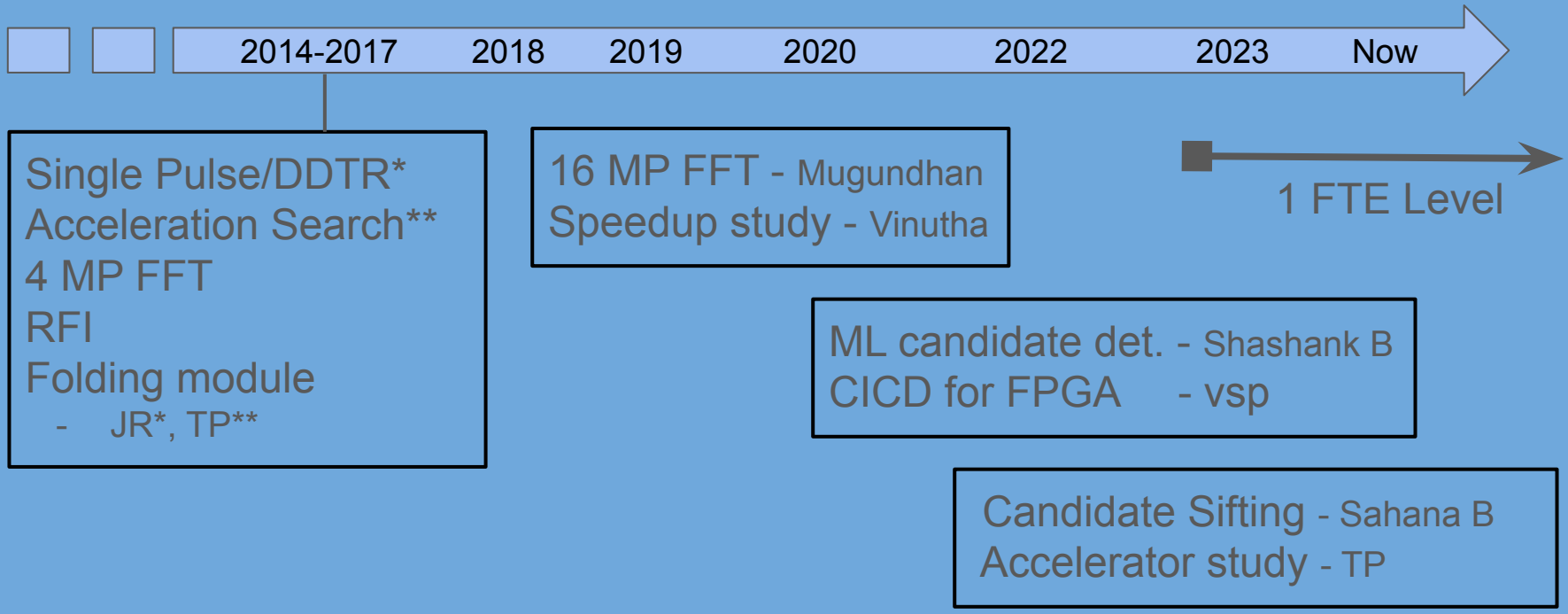
100 X



For illustration only

Server nodes with FPGA and GPU accelerators

Our Involvements so far



In journals

1. **High-performance computing for SKA transient search: Use of FPGA-based accelerators,**
   Arul P, Abhishek r, Sahana B, Vinutha, C, Mugundhan, J Mekhala M, J Roy, Prabu T along with PSS Team 2023, JoAA

2. **Median filters on FPGAs for infinite data and large, rectangular windows.**
   Krystine Dawn Sherwin, Kevin I-Kai Wang, Prabu Thiagaraj, Ben Stappers, and Oliver Sinnen.
   ACM Transactions on Reconfigurable Technology and Systems, 2022.

3. **FPGA-based acceleration of ft convolution for pulsar search using OpenCL.**
   Hamiao Wang, Prabu Thiagaraj, Oliver Sinon
   ACM Transactions on Reconfigurable Technology and Systems, 2019.

4. **Combining multiple optimized FPGA-based pulsar search modules using OpenCL.**
   Haomiao Wang, Prabu Thiagaraj, and Oliver Sinnen.
   Journal of Astronomical Instrumentation, 2019.

5. **Harmonic-summing module of SKA on FPGA at the irregular memory accesses.**
   Hamiao Wang, Prabu Thiagaraj, Oliver Sinon
   IEEE Transactions on Very Large Scale Integration (VLSI) Systems, 2019.

6. **FPGA-based acceleration of FT convolution for pulsar search using OpenCL**
   Haomiao Wang, Prabu Thiagaraj, and Oliver Sinnen, 2018

7. **Harmonic-summing module of ska on fpga–optimising the irregular memory accesses,**
   Haomiao Wang, Prabu Thiagaraj, and Oliver Sinnen, 2018.

8. **A GPU implementation of the correlation technique for real-time fourier domain pulsar acceleration searches.** Sofia Dimoudi, Karel Adamek, Prabu Thiagaraj, Scott M. Ransom, Aris Karastergiou, and Wesley Armour. The Astrophysical Journal Supplement Series, 2018.

Abstract

The Square Kilometre Array (SKA) is an upcoming, most sensitive radio telescope addressing significant scientific goals. It is being constructed by an international consortium involving academia and industry. The unprecedented sensitivity of the Square Kilometre Array (SKA) telescope will enable the investigation of areas as diverse as the formation of Earth-like planets, the detection of gravitational distortions of Spacetime, the origin of cosmic magnetic fields, and the formation and growth of Black Holes. SKA will have immense sensitivity to detect highly accelerated pulsar systems and other transients (FRB). The timing studies of the pulsed radio emissions from these distant millisecond pulsars directly investigate the spacetime metrics, which have opened a new window to explore Gravitational Wave Astronomy.

The signal flow in SKA involves conditioning and digitising antenna signals, transporting them to correlator-beamformers, and distributing output products using a global network to SKA Regional Centres (SRCs) located globally. The SRCs will assist user communities in accessing data products and analysis tools.

Searching for fast Transients from radio telescope data requires accounting for various distances, orbital periods, rotation periods, pulse widths, and also dealing with the interferences. SKA telescopes will generate enormous pulsar search data, with approximately 60 petabytes of data to be handled daily, requiring a mammoth computational capability of 10 Peta-operations per second to reduce the data in real-time. Such complex processing requirements necessitate exploring high-performance computing options and using novel accelerators based on modern FPGAs.

There are ongoing contributions from team members worldwide to develop a suitable real-time pipeline, as well as its integration and validation. This talk outlines the details of the SKA Fast Transient search pipeline, including the accelerated pulsar search pipeline for the SKA.

Thank you