SQUARE KILOMETRE ARRAY

Exploring the Universe with the world's largest radio telescope

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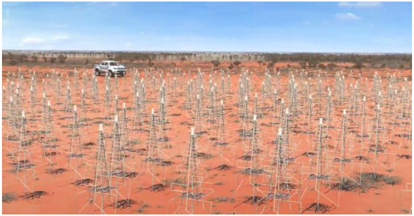
NCRA • TIFR

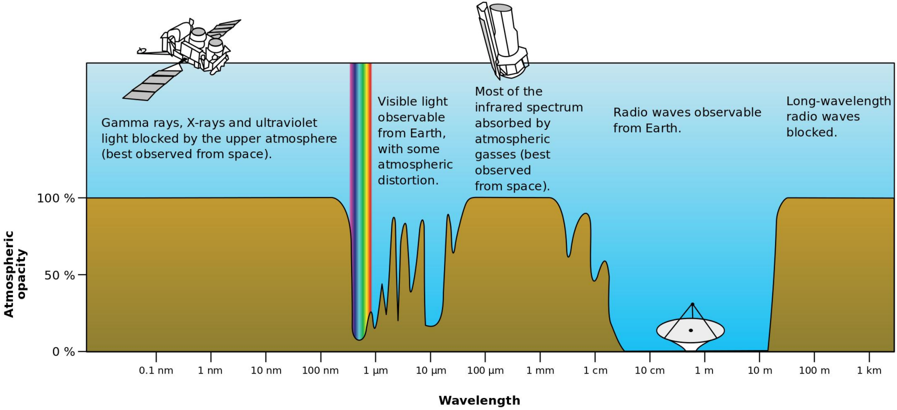
Outreach Programme on
Different Aspects of Astroparticle Physics and Cosmology
Saha Institute of Nuclear Physics, Kolkata
13 October 2015

Summary: Square Kilometre Array

- SKA is a large "array" of dishes and dipoles
- Once built (in 2020), it will be **the largest radio telescope ever built**
- It will answer some fundamental questions in astrophysics, cosmology and fundamental physics, starting from studying the first stars in the Universe to testing Einstein's theory of gravity



Radio frequency: smallest energies probed



Challenges in radio frequencies

- Radio frequency: $\nu \lesssim 300$ GHz, $\lambda \gtrsim 1$ mm.
- FM radio (~ 100 MHz), TV stations (bands in $\sim 50 - 200$ MHz)
- Mobile phones (bands in $\sim 800 - 2000$ MHz)
- Satellites, e.g., GPS ($\gtrsim 1$ GHz)
- Air traffic communication ($\sim 100 - 500$ MHz)
- Ionosphere: distorts radio waves coming to us, reflects radiation $\nu \lesssim 10$ MHz.

Dish antenna

Arecibo (Puerto Rico)

Parkes Radio Telescope (Australia)

Performance of telescopes

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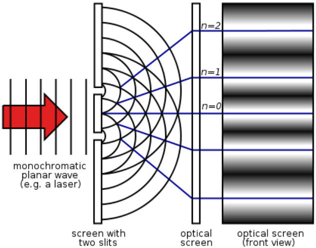
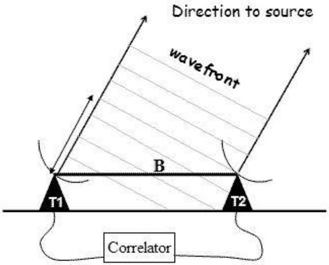
- To compete with optical telescopes, one needs to build dishes of diameter $\sim 100\mathrm{km}$!

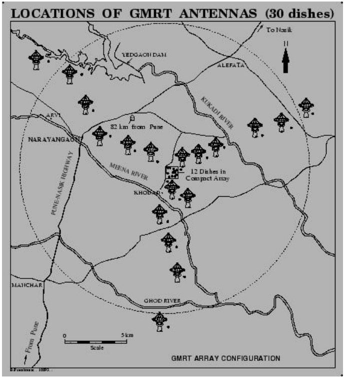
Concept of interferometry





- resolution $\Delta\theta \sim \lambda/d$, where d is now the distance between two dishes
- d can be as large as $\sim 50 - 100$km.

Radio interferometric arrays: GMRT



- **Giant Metrewave Radio Telescope**
- 30 antennas, 45 m diameter each. works in frequency range $\approx 150 - 1400$ MHz
- situated at *Narayangaon*, about 80 km from Pune.
- Currently being upgraded to uGMRT, one of the SKA pathfinders

Radio interferometric arrays: VLA

- Very Large Array
- New Mexico, USA
- 27 antennas, 25 m diameter each.

Other radio interferometric arrays

Low-Frequency Array (LOFAR):

Murchison Widefield Array (MWA):

Square Kilometre Array Phase 1

SQUARE KILOMETRE ARRAY

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 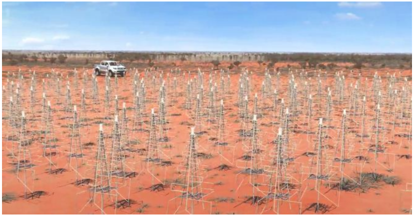

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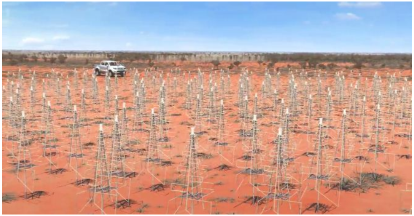

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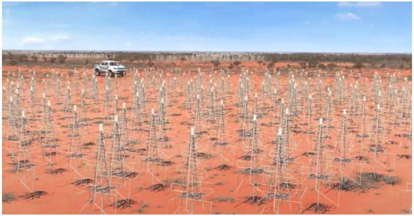

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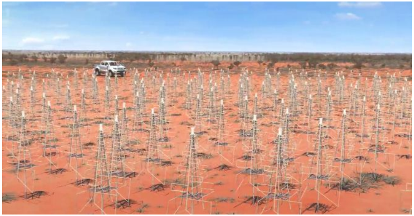

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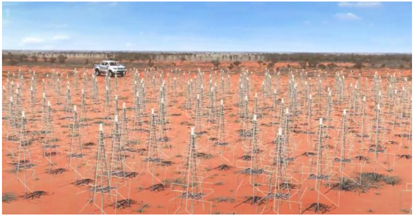
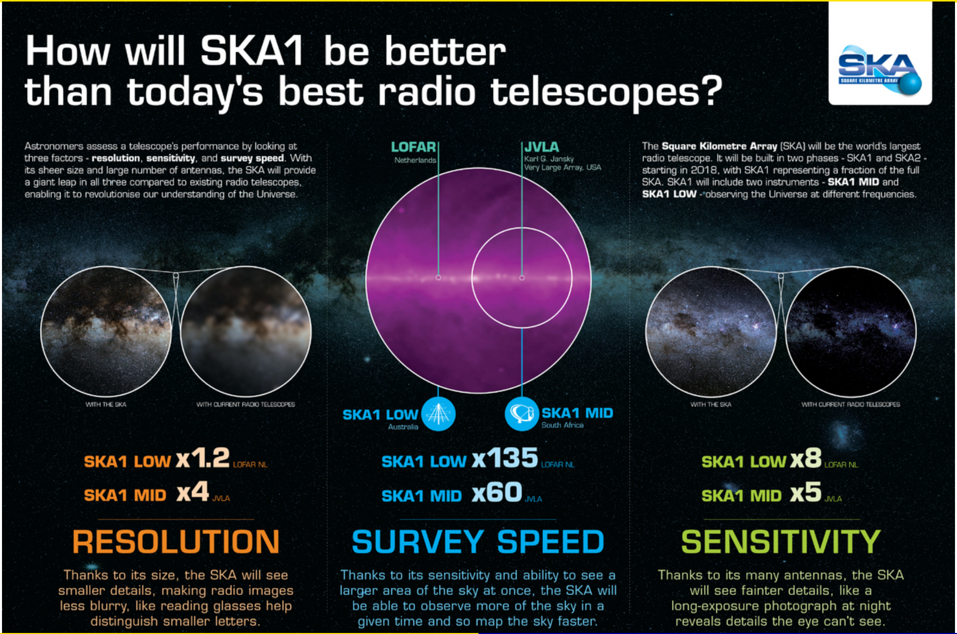
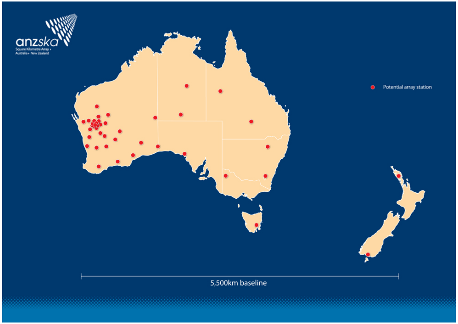
- effective collecting area $\sim$ km$^2 = 10^6$ m$^2 \sim 5 - 10$ times more collecting area than any existing telescope!

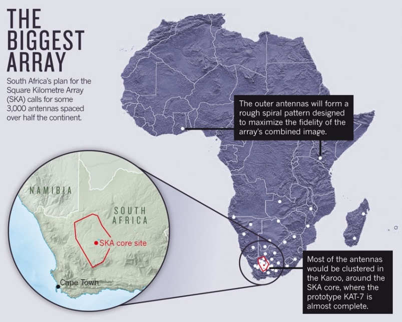


SKA1 compared to other telescopes



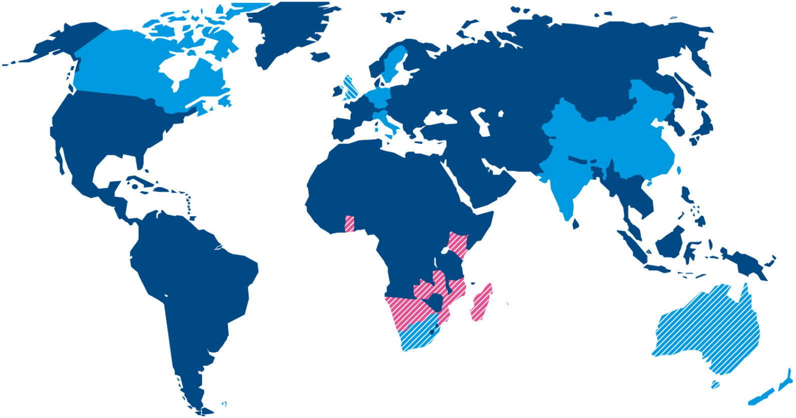
SKA: sites





- Very low population density
- Large amount of empty space
- Western Australia, Karoo desert (South Africa)

Countries participating in the SKA



Full members

SKA Headquarters host country

SKA Phase 1 and Phase 2 host countries

African partner countries
(non-member SKA Phase 2 host countries)

This map is intended for reference only and is not meant to represent legal borders

SKA: Indian involvement

The Telegraph

India in radio telescope club

OUR SPECIAL CORRESPONDENT

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Several academic institutions led by the National Centre for Radio Astronomy (NCRA), Pune, will contribute to the design and operations of the Square Kilometre Array (SKA) to be co-located in Australia and South Africa and expected to become operational in the early-2020s.

(Left) An illustration of dish antennas at a site in South Africa; an illustration of low-frequency receivers at the SKA site in Australia

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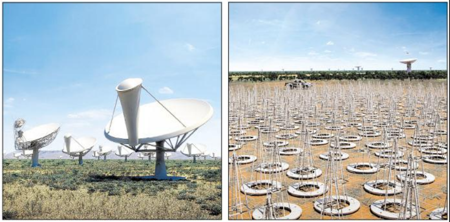

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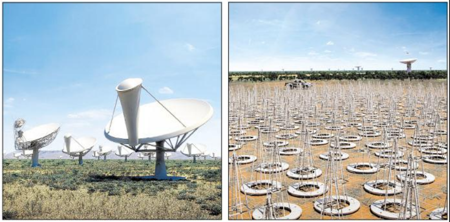

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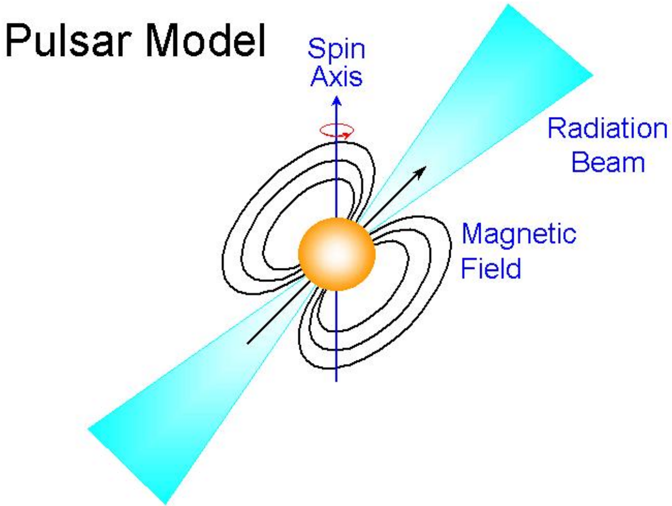
- 13 organisations are members of the Consortium



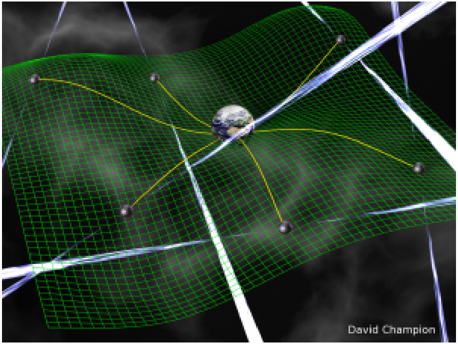
excellent clocks, precise timing
SKA1 will detect a large number of pulsars

Gravitational waves

- Einstein's theory of gravity predicts that the space-time is curved by the presence of matter / energy
- Gravitational waves are ripples in the curvature of space-time, propagating with a speed c

Pulsar timing arrays

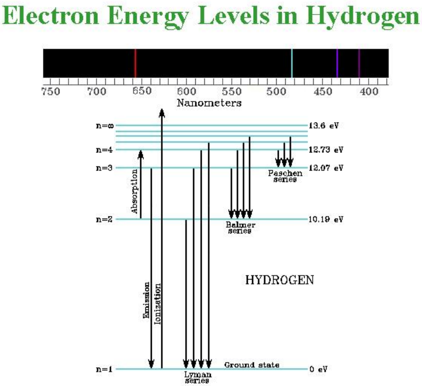
- Identify a set of pulsars in different directions, and study their timing
- When a gravitational wave passes between the earth and the pulsars, it distorts the space-time, thus affecting the time of arrival of the pulses
- This feature can be used to detect gravitational waves



Science with the SKA: low frequency transitions

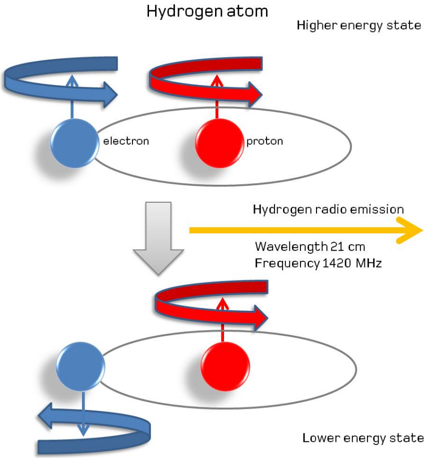
- The most interesting (quantum) transitions for radio telescopes are the ones that have small energy difference
- For example, take electronic transitions of the hydrogen atom:

$$\Delta E = 13.6 \text{ eV} \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right) \Longrightarrow \nu = \frac{\Delta E}{h} \approx 3 \times 10^{15} \text{ Hz} \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$



- Take $n_1 = 100$ and $n_2 = 101$, then $\nu \sim 2$ GHz. This happens when an electron (re-)combines with the proton at a high n and cascades downwards. These are called radio recombination lines.
- Other interesting transitions are rotational and vibrational ones of more complex atoms/molecules.

Spin-flip transition of hydrogen (21 cm line)



The transition is not possible when hydrogen is ionized!

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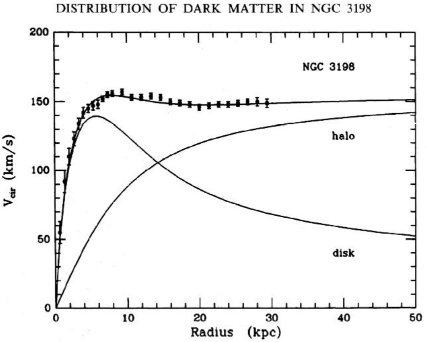

$$v_c^2(r) = \frac{GM(r)}{r} \implies$$

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Proof of dark matter!

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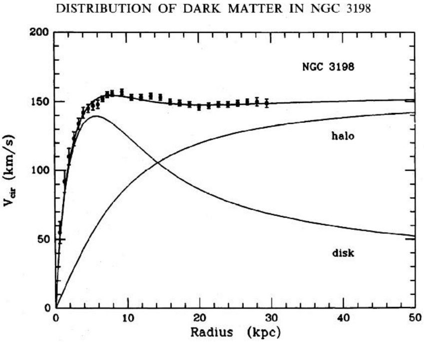

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- Cosmology: plans to probe the era when the Universe lit up!

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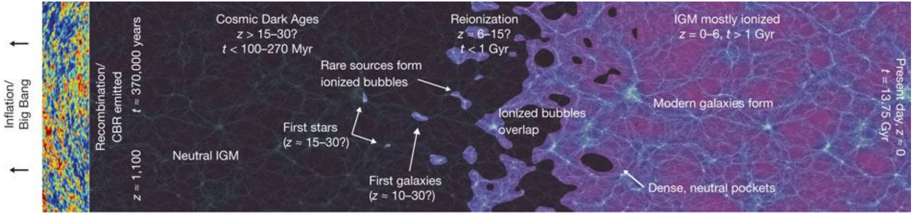

Concept of Dark Ages, Cosmic Dawn, Epoch of Reionization.

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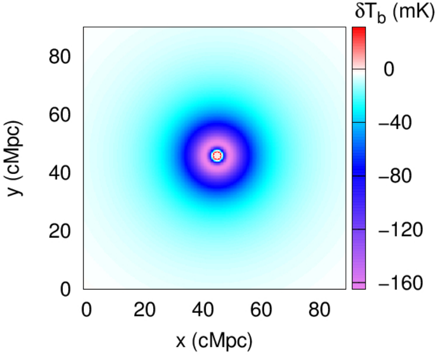
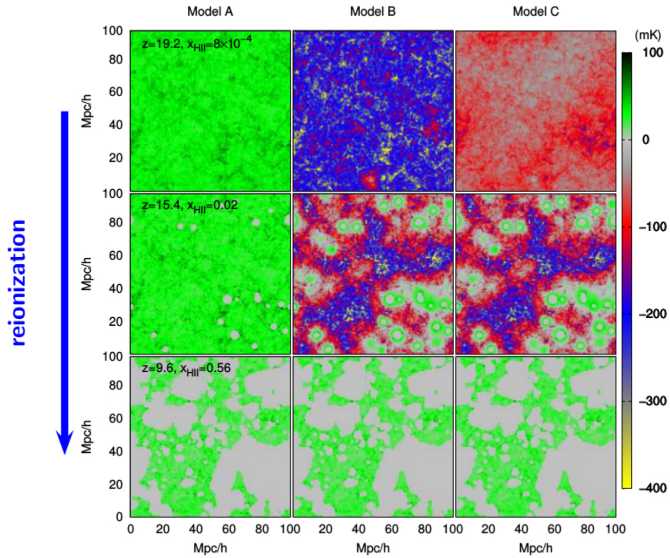
- Major science goals for LOFAR, MWA and SKA1-low!



Ghara, **Choudhury** & Datta (2015)

Radio maps with many stars



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- Looking for bright, enthusiastic students to make contribution.

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