

SKA Precursors and Pathfinders



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A square kilometre of collecting area for each of three frequency bands

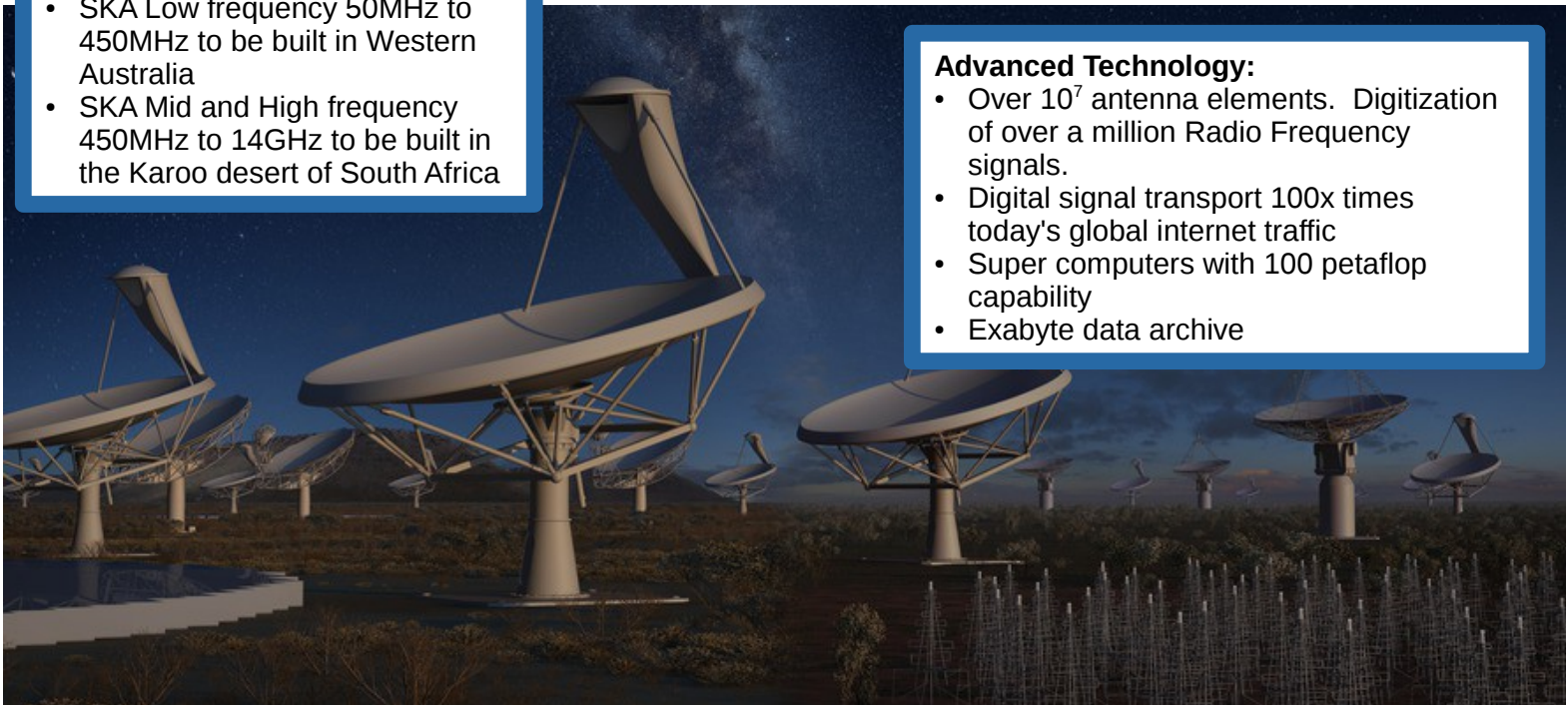
- SKA Low frequency 50MHz to 450MHz to be built in Western Australia
- SKA Mid and High frequency 450MHz to 14GHz to be built in the Karoo desert of South Africa

Fundamental Physics:

- The formation of large scale structure and the first luminous objects
- The distribution of mass in the Universe and the nature of the Dark Energy
- The origin of magnetic fields in the Universe
- The limits of General Relativity
- Gravitational Waves from black hole mergers and possibly from the Big Bang
- The formation of planetary systems and the detection of bio markers (pre-biotic molecules, artificially generated transmissions from ETI)
- Transient phenomena at very fast time scales (Bursts from Active Galactic Nuclei and others)

Advanced Technology:

- Over 10^7 antenna elements. Digitization of over a million Radio Frequency signals.
- Digital signal transport 100x times today's global internet traffic
- Super computers with 100 petaflop capability
- Exabyte data archive





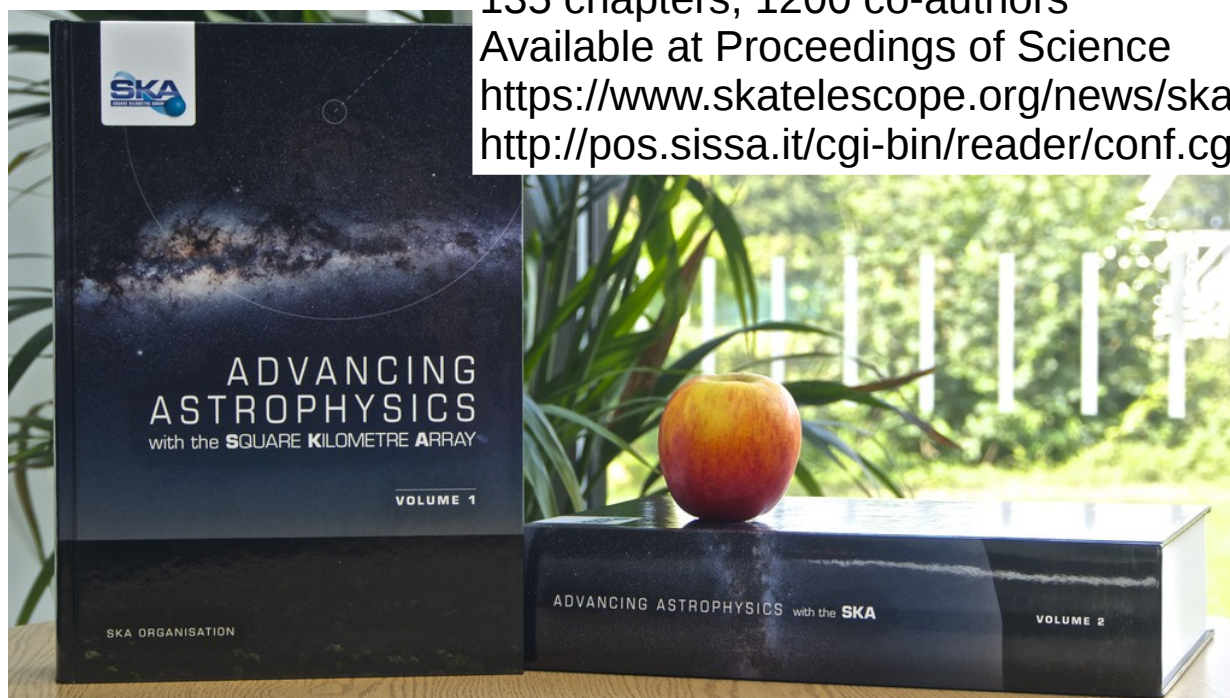
SKA Science Book

135 chapters, 1200 co-authors

Available at Proceedings of Science

<https://www.skatelescope.org/news/ska-science-book/>

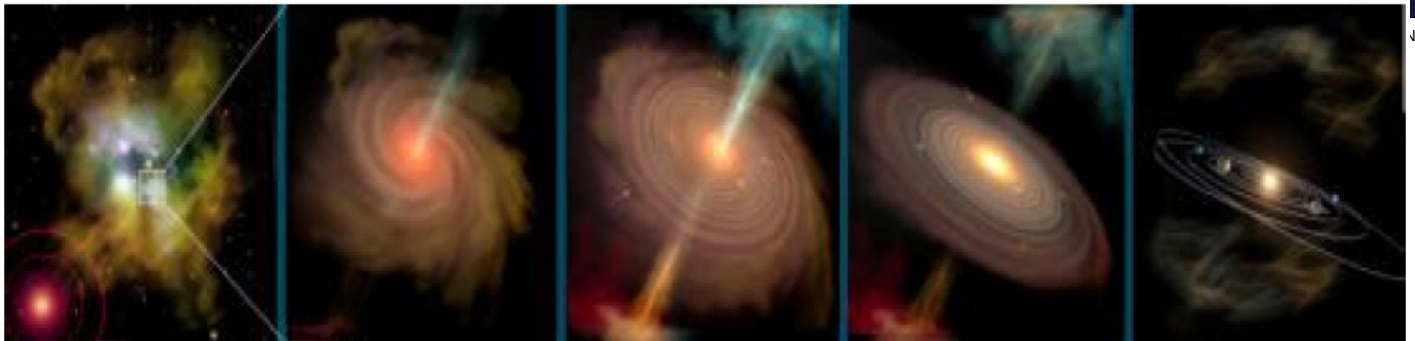
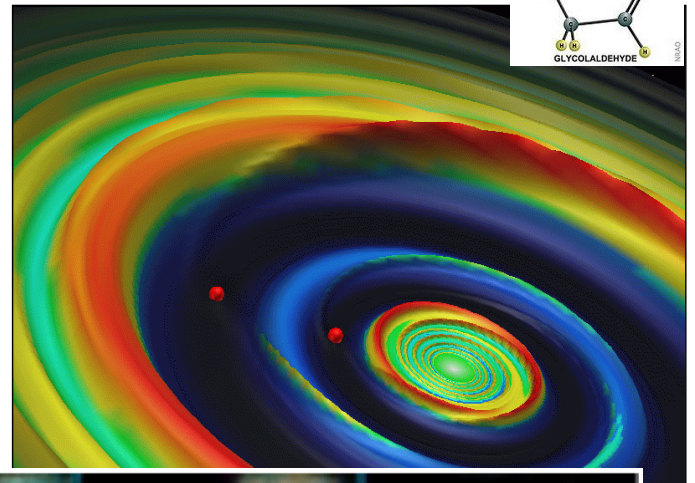
<http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=215>





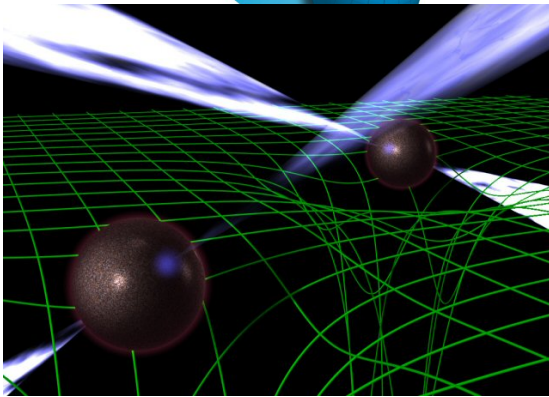
Cradle of Life

- Protoplanetary disks resolved to Earth-like orbits
- Organic molecules
 - methanol (834 MHz)
 - acetaldehyde (1.1 GHz)
 - acetamide (9.2 GHz)
 - cyclopropenone (9.3 GHz)
- Extrasolar planets

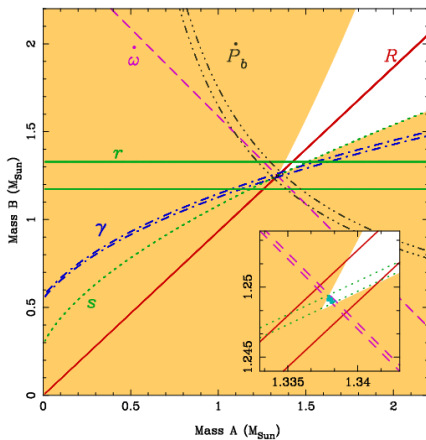




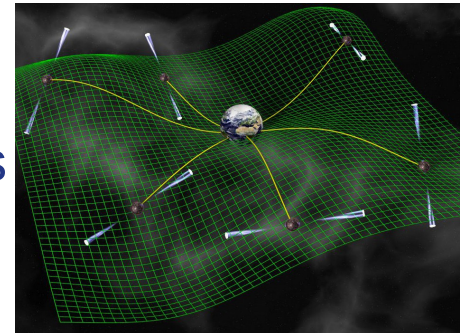
Tests of Gravity with Pulsars



Relativistic effects measured by timing pulsar “clock” ticks permit (re) determination of binary masses.



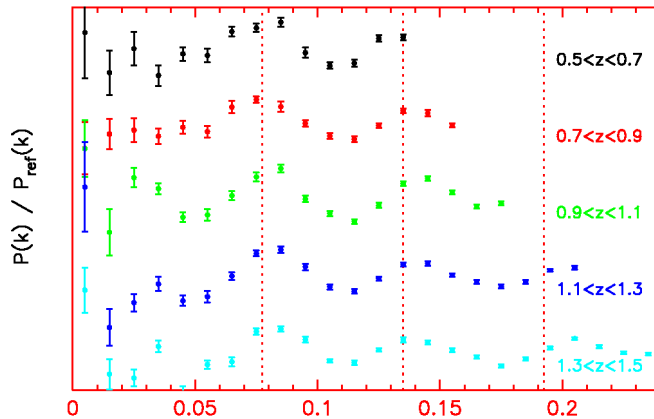
Pulsar timing array will detect Gravitational Waves of nHz (galactic length scale)



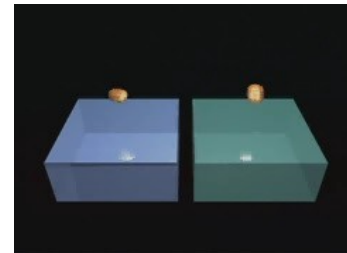
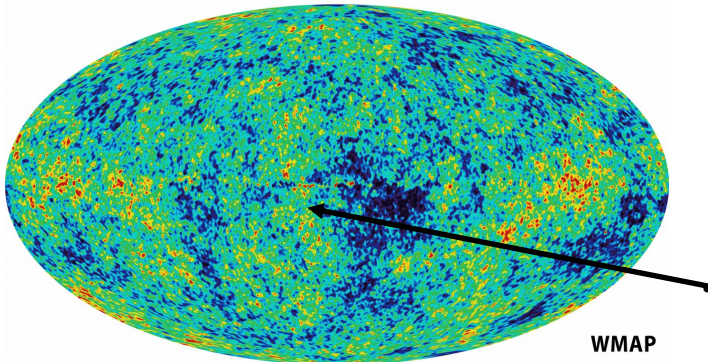


Dark Energy

Baryonic Acoustic Oscillations



BAO signature traces the length scale of the Universe at different epochs. This gives the evolution of Dark Energy and the Equation of State of the Universe.



There are fluctuations at all scales but there is a preferred scale of around 1 deg.

Science Requirements



Translating Science Requirements to Technical Specifications

Redshift, velocity
dispersion, survey
extent and
precision,
sensitivity,...



Frequencies,
spectral resolution,
Field of View,
angular resolution,
system
temperature,...

Torchinsky et al. (2016) [arXiv:1610.00683](https://arxiv.org/abs/1610.00683)

SKA Pathfinders and Precursors

Precursor

An instrument operating on one of the SKA sites which has a direct relevance/influence to the SKA design

Pathfinder

SKA-related technology, science and operations activity

<https://www.skatelescope.org/technology/precursors-pathfinders-design-studies/>

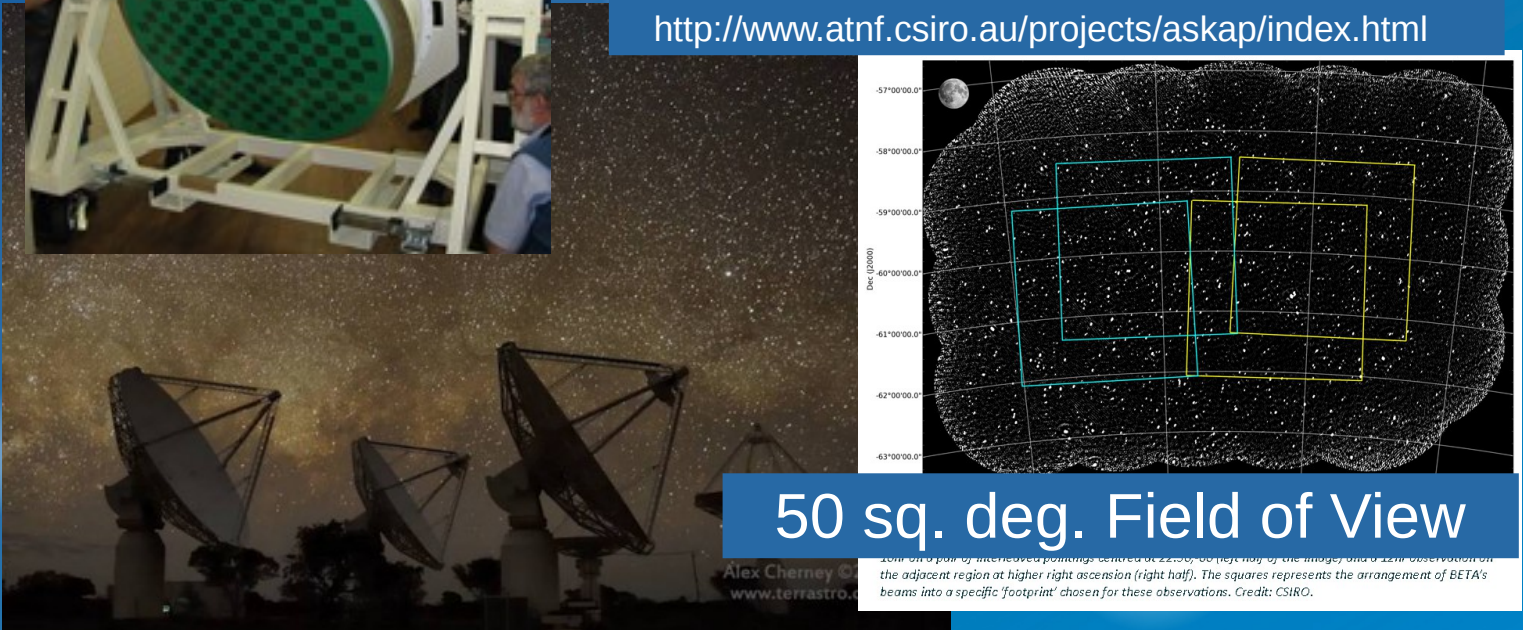
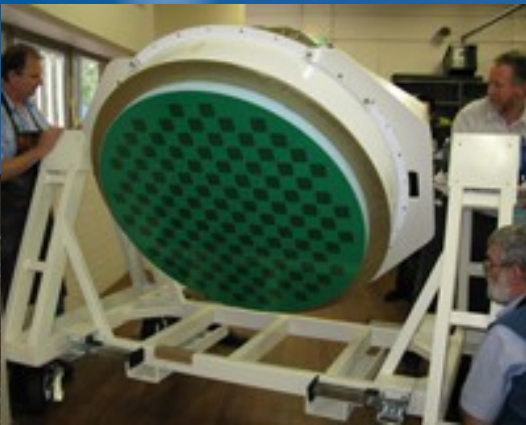
4 precursor instruments, and 13 pathfinders

ASKAP

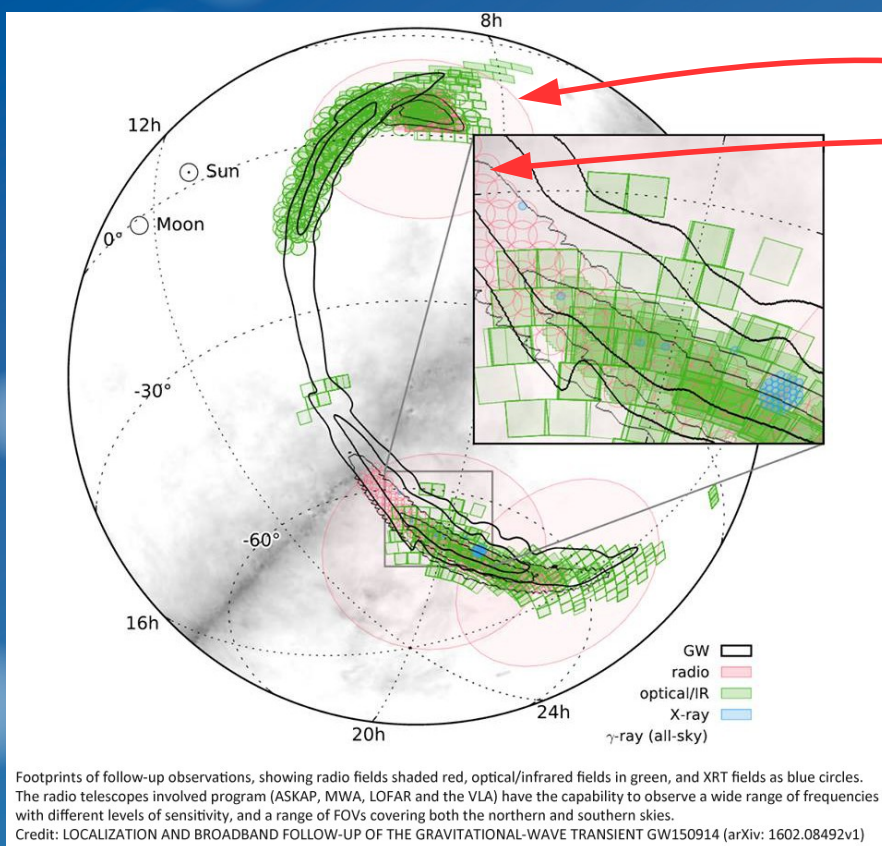
Australia SKA Precursor

36 antennas, 12m diameter
Phased Array Feeds
700MHz to 1800MHz

<http://www.atnf.csiro.au/projects/askap/index.html>



ASKAP Follow-up for LIGO



Radio follow-up by ASKAP, MWA, LOFAR, and Jansky VLA

Astrophysical Journal Letters, 826, L13. (2016)

MeerKAT



The Bigger Karoo Array Telescope
South Africa

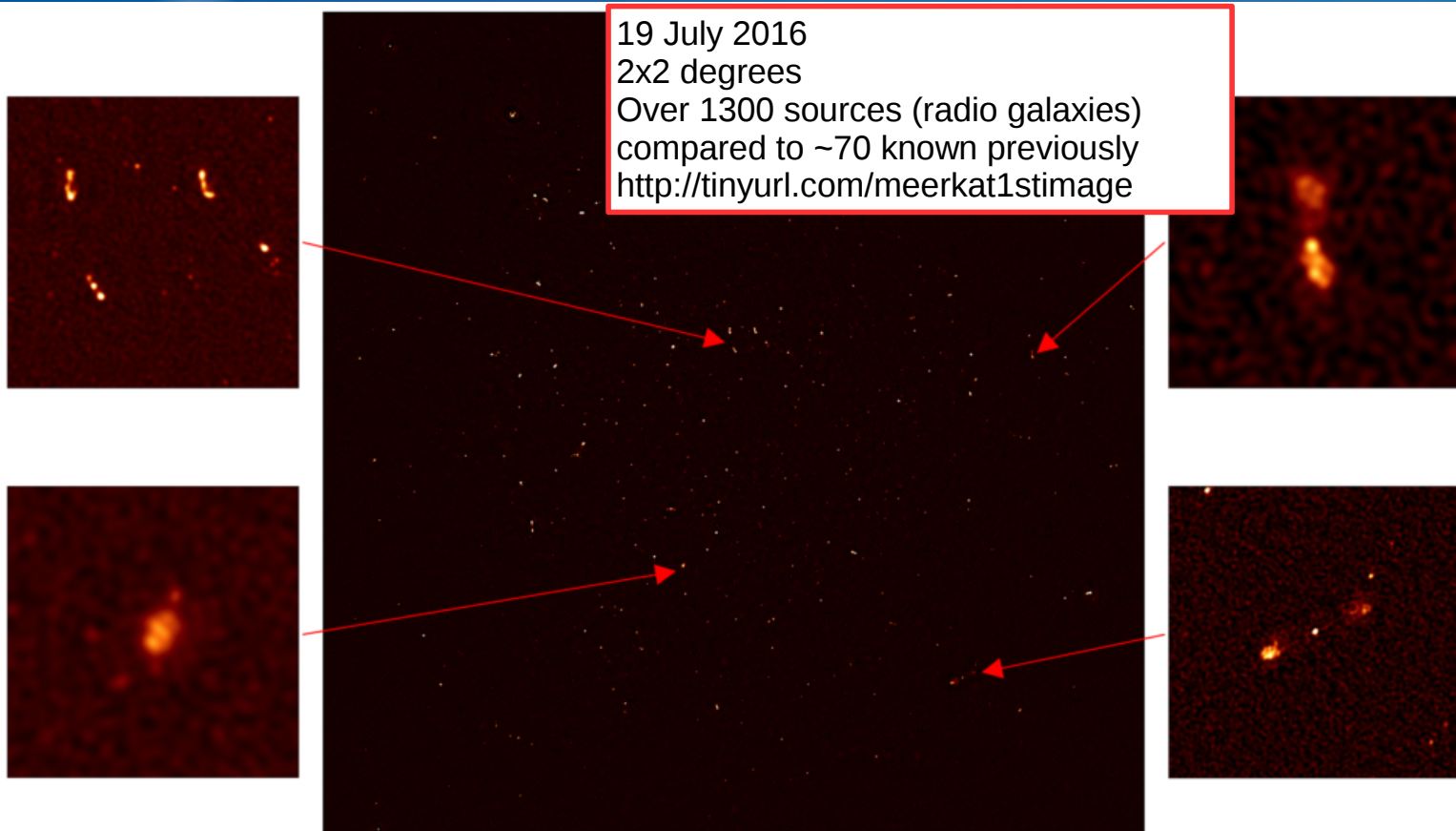
64 antennas, 13.5m diameter

Single pixel feeds

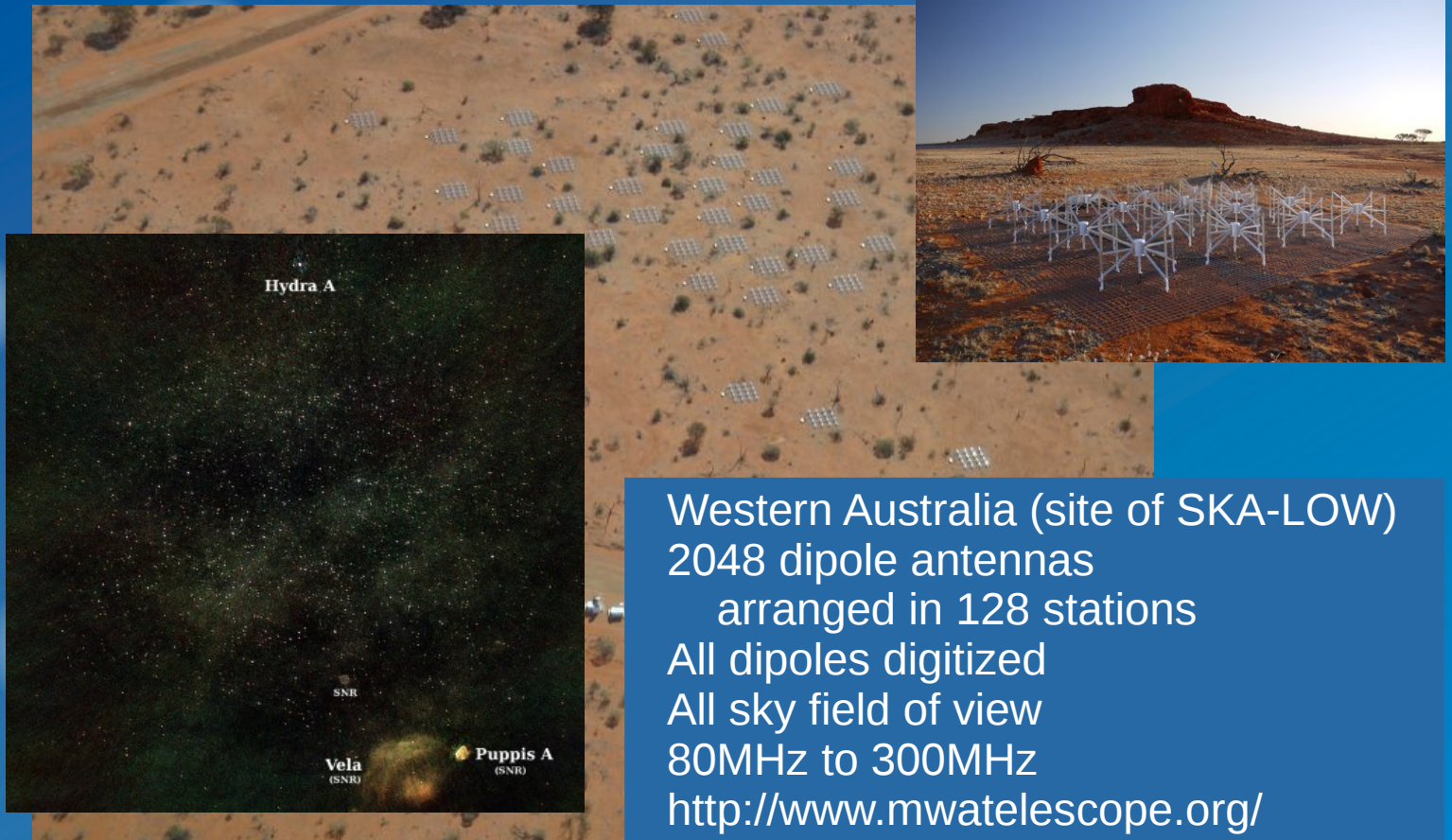
1000MHz to 1750MHz

<http://www.ska.ac.za/meerkat/index.php>

First Image with MeerKAT (16 dishes)

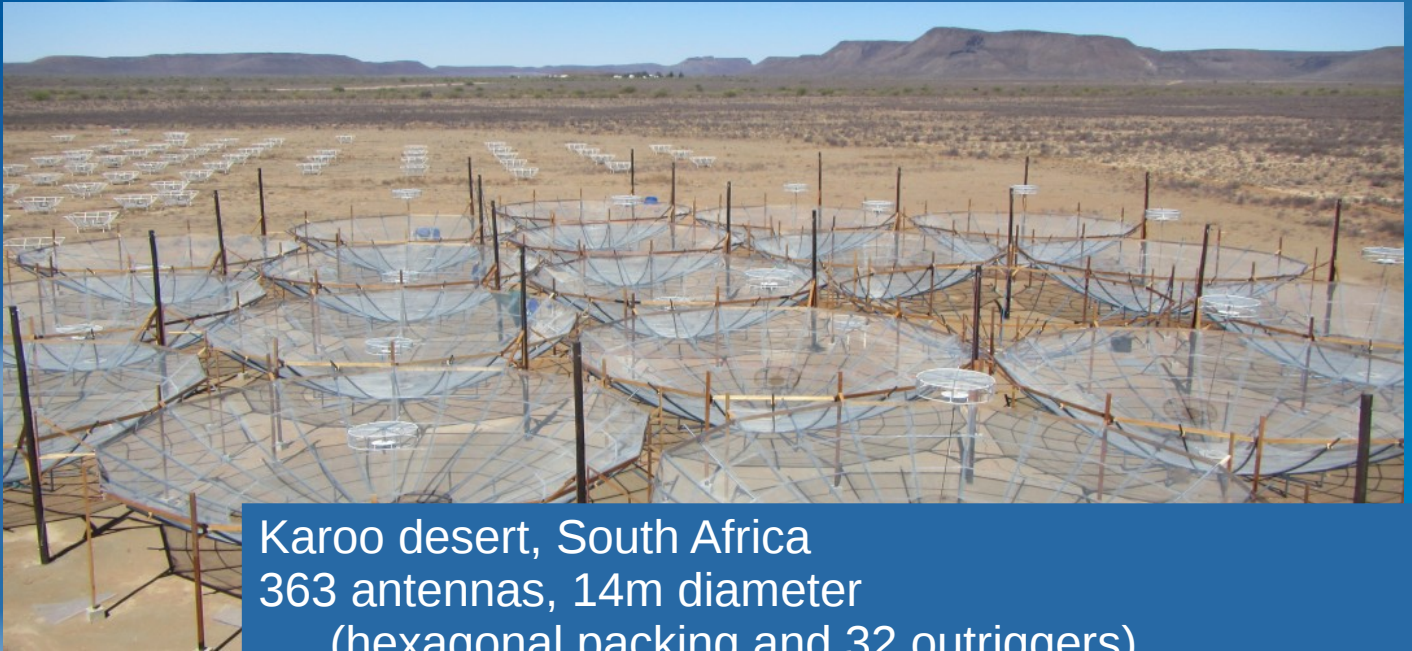


Murchison Widefield Array



Western Australia (site of SKA-LOW)
2048 dipole antennas
arranged in 128 stations
All dipoles digitized
All sky field of view
80MHz to 300MHz
<http://www.mwatelescope.org/>

Hydrogen Epoch of Reionization Array



Karoo desert, South Africa
363 antennas, 14m diameter
(hexagonal packing and 32 outriggers)
120MHz to 190MHz
<http://reionization.org/>

SKA Pathfinders

Pathfinders

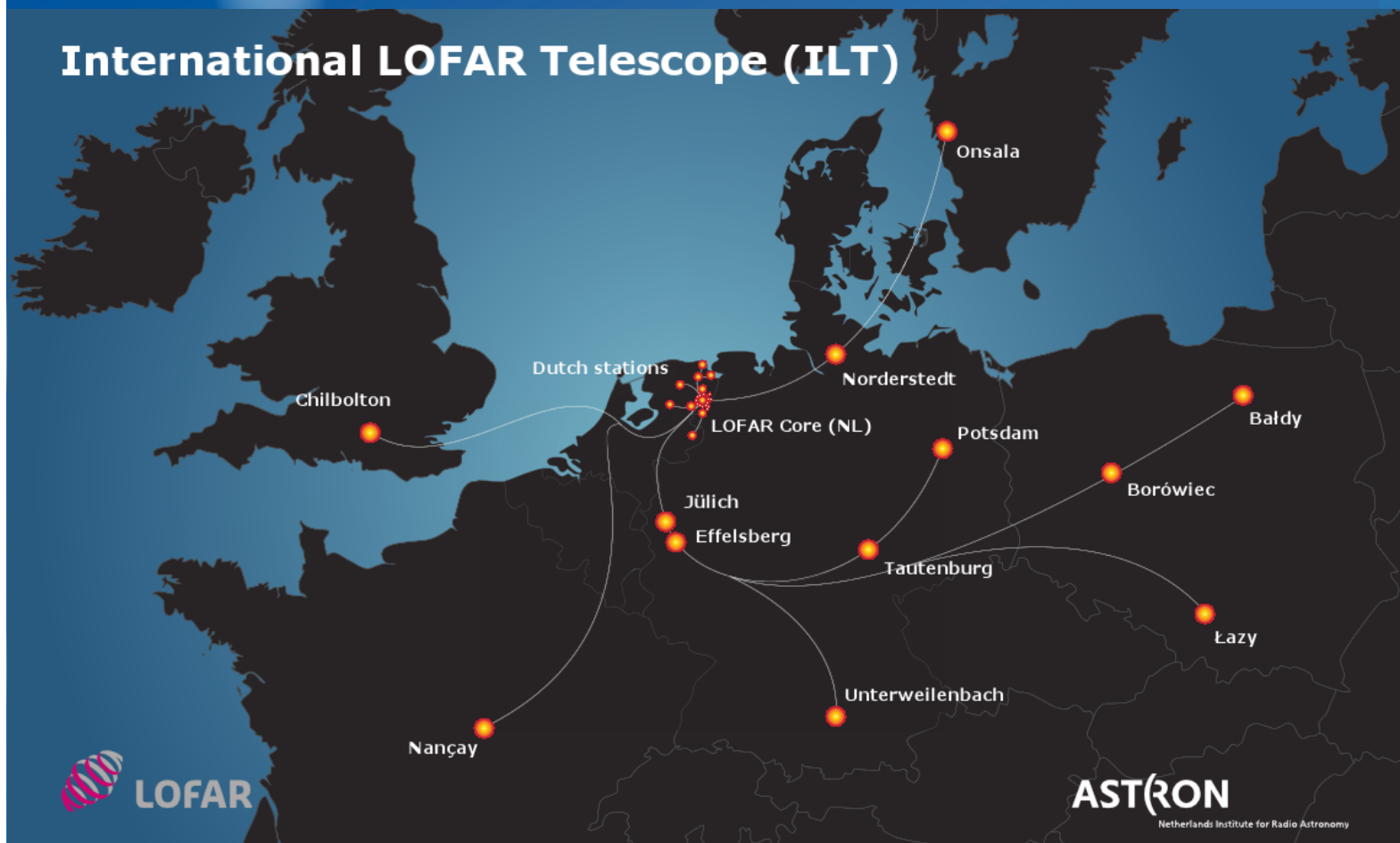
Pathfinder telescopes and systems, dotted around the globe are also engaged in SKA related technology and science studies. These include the famous Arecibo radio telescope in Puerto Rico, which starred in the James Bond movie “Goldeneye”, the LOFAR low frequency array, which is based in Europe, and the EVLA, in North America, which was famously seen in the hit movie “Contact”. Here is a list of SKA Pathfinders;

- APERTure Tile In Focus (APERTIF), The Netherlands
- Arecibo Observatory, Puerto Rico
- Allen Telescope Array (ATA), USA
- electronic European VLBI Network (eEVN), Europe
- Electronic MultiBeam Radio Astronomy ConcEpt (EMBRACE), France & The Netherlands
- e-MERLIN, UK
- Expanded Very Large Array (EVLA), USA
- Giant Metrewave Radio Telescope (GMRT), India
- Low Frequency Array (LOFAR), The Netherlands
- Long Wavelength Array (LWA), USA
- NenuFAR, France
- Parkes Telescope, Australia
- SKA Molonglo Prototype (SKAMP), Australia



LOFAR

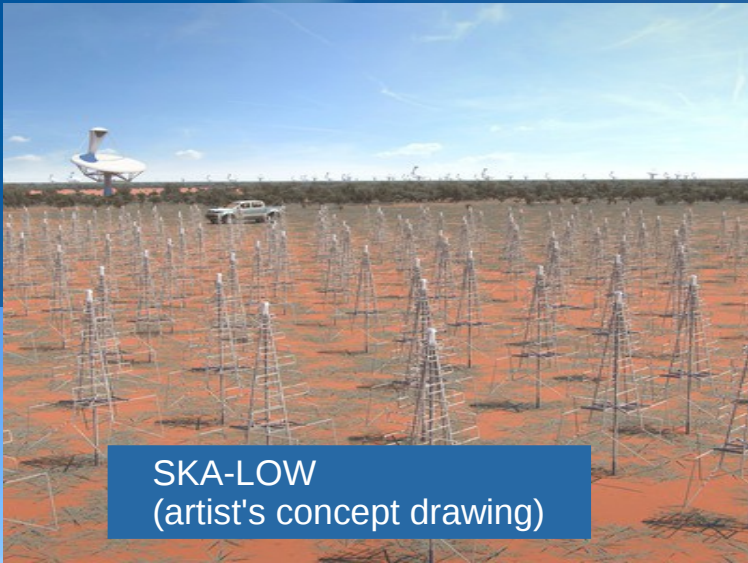
International LOFAR Telescope (ILT)



LOFAR

- Over 50000 antennas arranged in 50 stations distributed throughout Europe
- Longest baseline: ~1500km (Nançay - Onsala)
- The world's largest radio telescope in the band 30MHz – 240MHz
 - (gap from 90 - 110MHz because of FM radio)

NenuFAR Pathfinder for SKA-LOW



SKA-LOW
(artist's concept drawing)



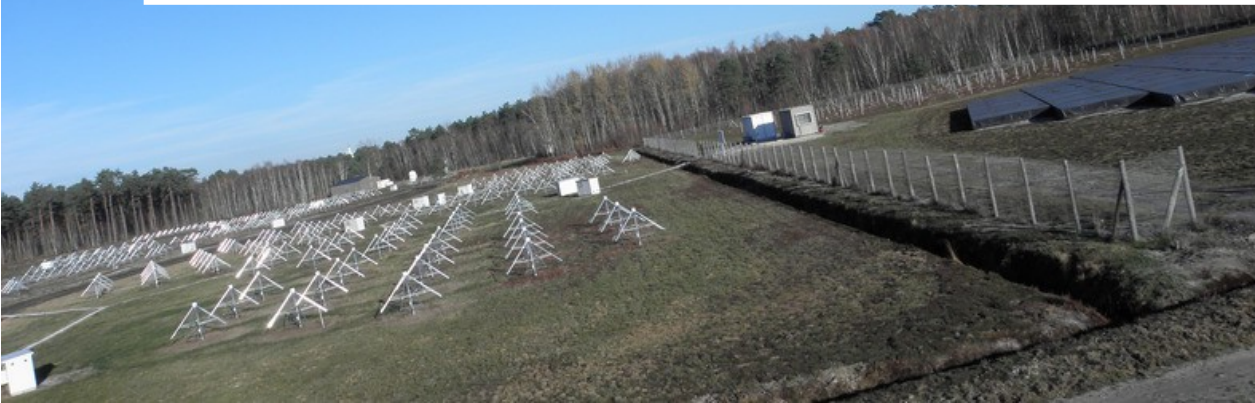
LOFAR at Nancay



NenuFAR at Nancay

NenuFAR

- 1824 dual polarization dipoles
 - 96 arrays of 19 antennas each
- 10-85 MHz
- Extends the band of LOFAR from 30MHz down to 10MHz
- On its own, a large low frequency instrument
- Working with LOFAR, provides the equivalent of a second “core” station
 - Improve LOFAR calibration
 - Independent core for remote stations



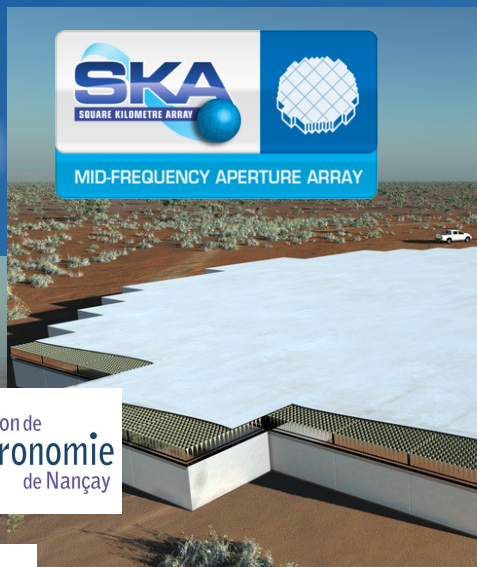
Electronic MultiBeam Radio Astronomy ConcEpt



ASTRON

l'Observatoire
de Paris

Station de
Radioastronomie
de Nançay



Beamformer Chip

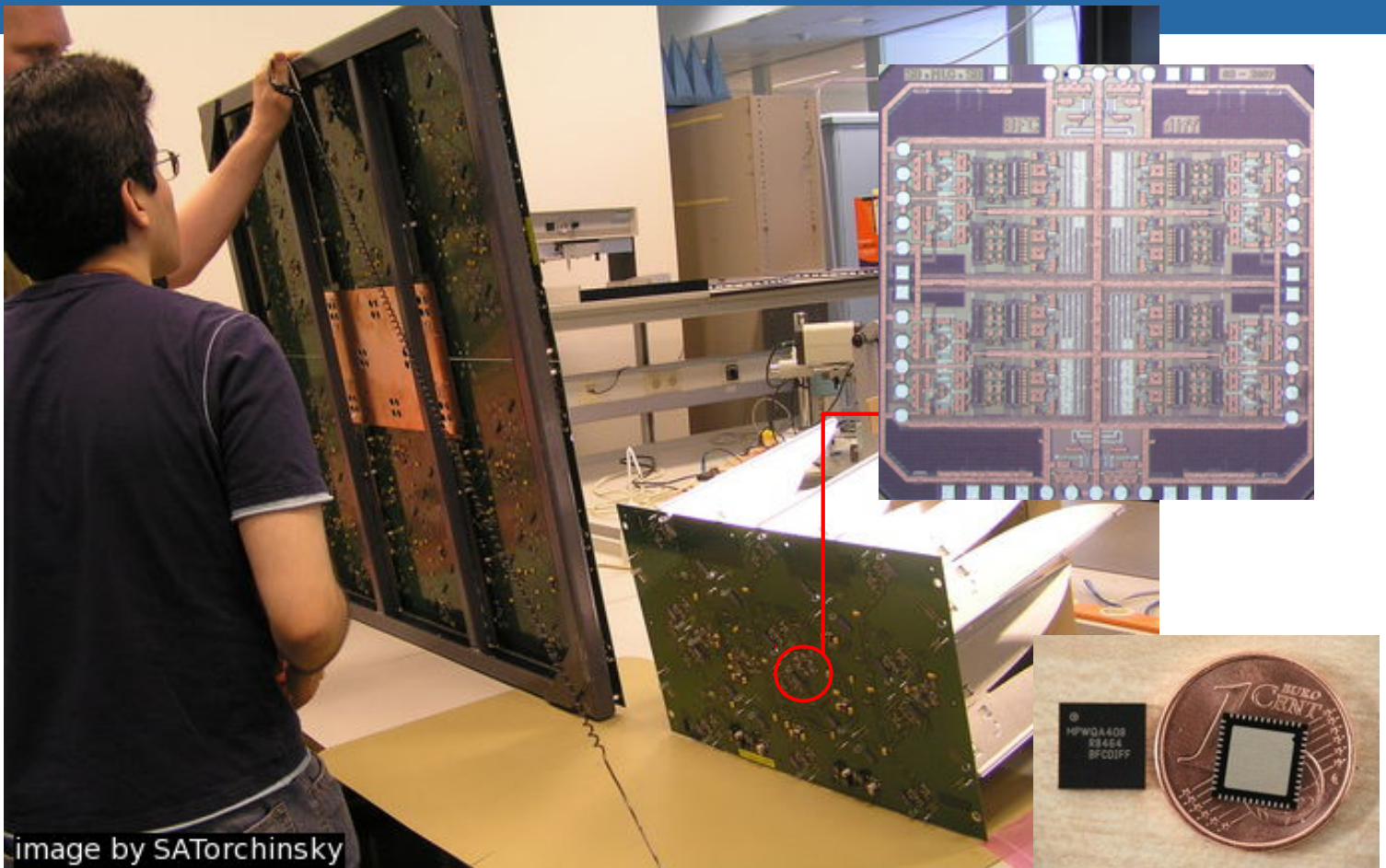


image by SATorchinsky

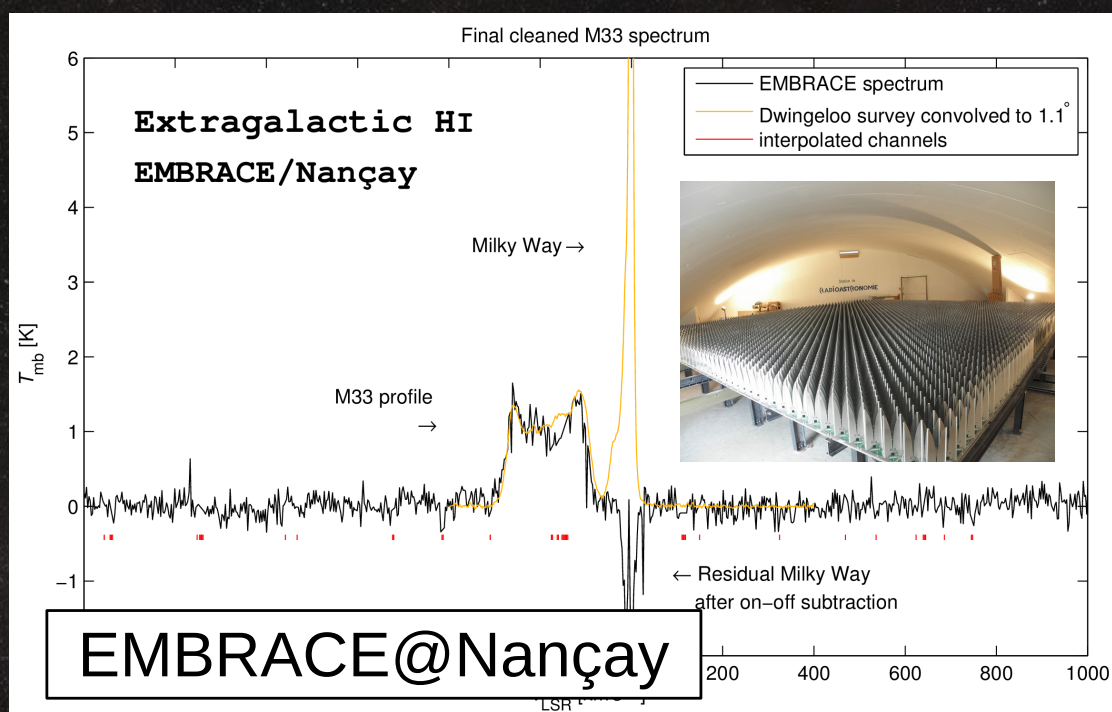
SKA Precursors and Pathfinders, Steve Torchinsky, Fermilab, 17 October 2016

EMBRACE Characteristics



- 4608 Vivaldi antenna elements
- Single polarization (second polarization antennas are in place, but only one polarization has a complete signal chain)
- 500 – 1500 MHz (but high pass filter at 900 MHz to avoid digital television)
- Instantaneous RF band: 100 MHz
- 70 m² (8.5m X 8.5m)
- Maximum instantaneous beam formed: 36 MHz x 2 directions
- Can trade off band width vs. number of beams
- 4 level hierarchical analog beamforming/signal summing
- Beamformer chip: 4 inputs, 2 outputs (2 independent beams), 45° phase steps
- 32 inputs to LOFAR backend (16 A-beam, and 16 B-beam)

Galaxy Detection



EMBRACE further information

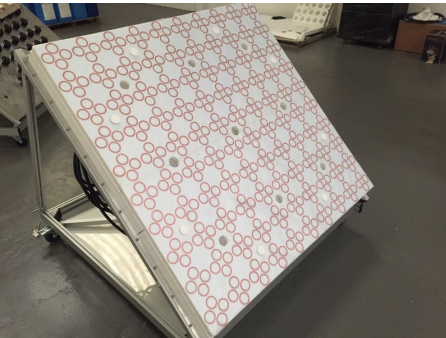


- <http://dx.doi.org/10.1051/0004-6361/201526706>
- Torchinsky et al, Astronomy & Astrophysics, 589, A77 (2016)

Future Developments

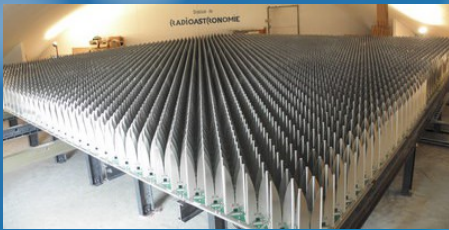


- Future development towards a large prototype
 - To be built on the SKA site in South Africa (seeking funding)
 - Various frontends proposed
 - Vivaldi array (EMBRACE)
 - Octogonal Ring Array
 - collaboration: Manchester/Nancay
 - LNA, beamformer chips, provided by Nancay
 - INFIERI ESR working on design and testing at Nancay (Tailei Wang)



Pathfinder value

- Small prototype but big enough to do astronomy and validate the concept (EMBRACE)
- Large prototype with advanced scientific capability (NenuFAR)
- World class instrument (LOFAR)
- Learn about the complexities associated with a new technology (calibration, operation)
- Long term behaviour (mean time between failure)
- Confidence that the technology is mature (risk mitigation)
- Experience with pathfinder is used to design production version



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