NenuFAR as a SKA Pathfinder

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SKA Definitions

Precursor

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

Pathfinder

A radio astronomy instrument in operation which has a direct relevence/influence to the SKA design.

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

SKA Precursors

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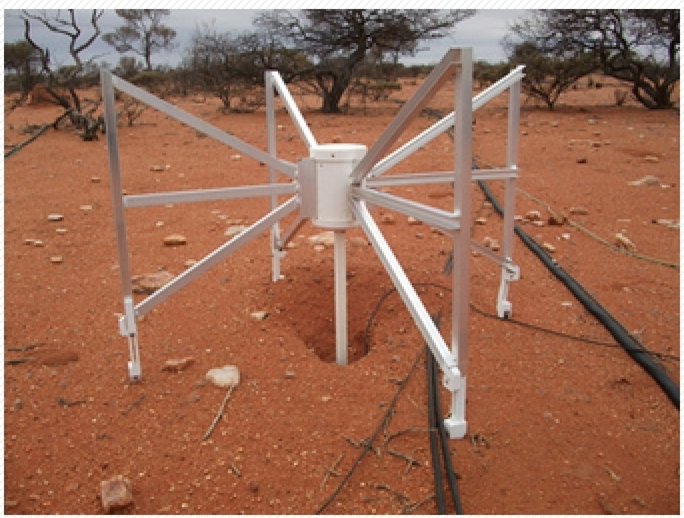
Precursors, Pathfinders And Design Studies

Precursor telescopes like the South African MeerKAT and the CSIRO's Australian SKA Pathfinder (ASKAP) and Murchison Widefield Array (MWA) are providing SKA scientists with invaluable knowledge to assist in the design of the SKA's main telescopes over the coming decade.

Did you know?

The SKA will be so sensitive that it will be able to detect an airport radar on a planet 50 light years away.



The Murchison Widefield Array (C) CSIRO

The Murchison Widefield Array, shown in the image above is just one of the many telescopes contributing to the final SKA in terms of scientific and technical input

Located at future SKA sites, these precursors are and will be in future carrying out scientific study related to future SKA activities, as well as helping the development and testing of new crucial SKA technologies..

MeerKAT, which is currently taking sh
Africa's Karoo region, will be a world

Precursor facilities

- Australian SKA Pathfinder (ASKAP)
- MeerKAT
- Murchison Widefield Array (MWA).

SKA Pathfinders

Pathfinders

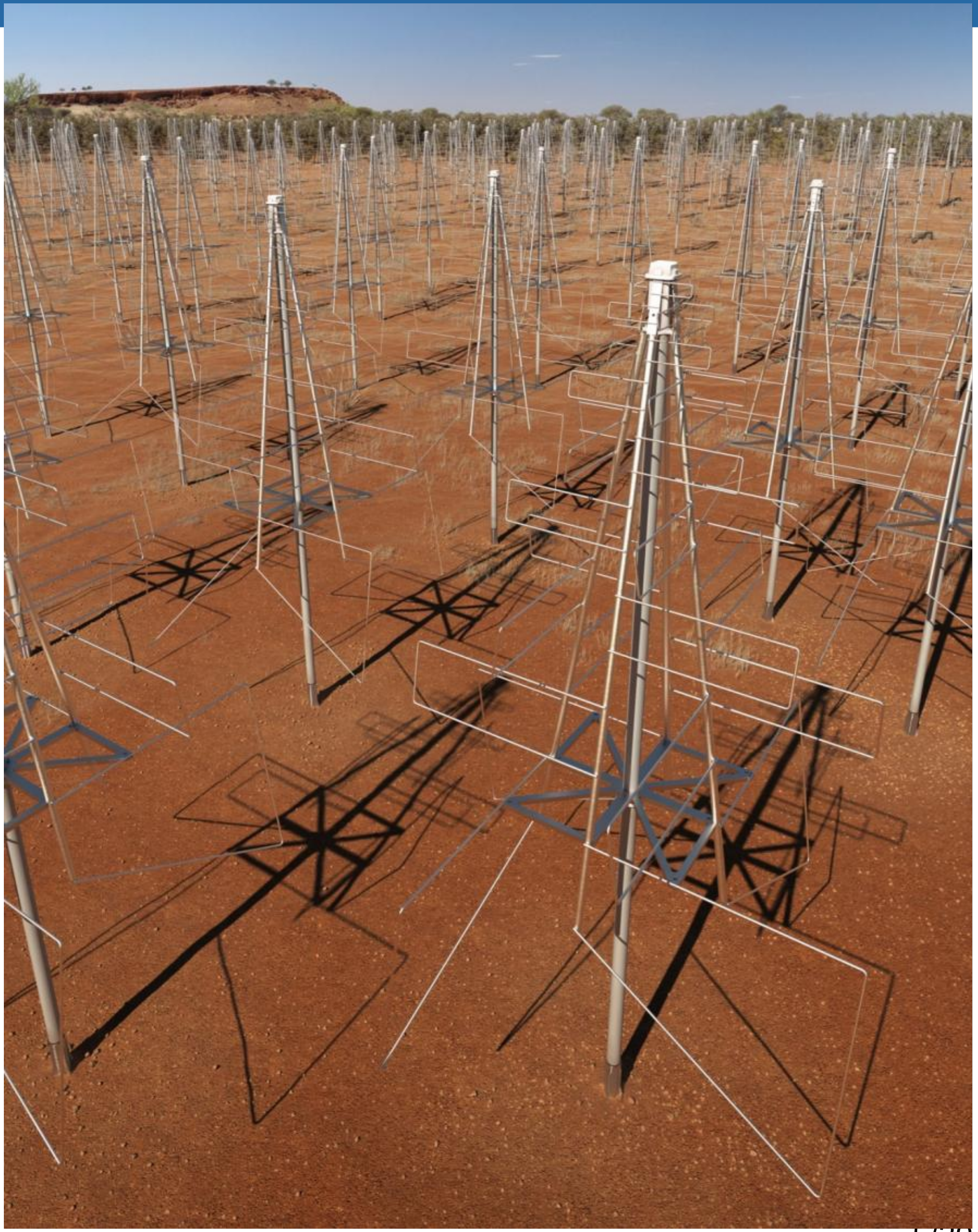
Pathfinder telescopes and systems, dotted around the globe are also engaged in SKA related technology and science studies. These include the famous Arecibo radio telescope in Puerto Rico, which starred in the James Bond movie "Goldeneye", the LOFAR low frequency array, which is based in Europe, and the 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)
- Arecibo Observatory
- Allen Telescope Array (ATA)
- electronic European VLBI Network (eEVN)
- Electronic MultiBeam Radio Astronomy ConcEpt (EMBRACE)
- e-MERLIN
- Expanded Very Large Array (EVLA)
- Low Frequency Array (LOFAR)
- Long Wavelength Array (LWA)
- SKA Molonglo Prototype (SKAMP).

SKA Low Phase 1
Baseline performance requirements (in brief)

Strongly configured for EoR

Frequency:	50MHz – 350MHz
Bandwidth:	300MHz
Sensitivity :	1000m^2/K (110–350MHz)
Polarisation:	Dual (of good quality)
Beam size:	>5° (no beam stitching)
Scan angle:	45°max. (Usable for EOR) *(beamformer 60°)*
# of beams:	1
Configuration:	50% <600m radius 75% <1km radius 95% <3km radius 3 spiral arms of 50km
Data rate:	~10Tb/s (total)



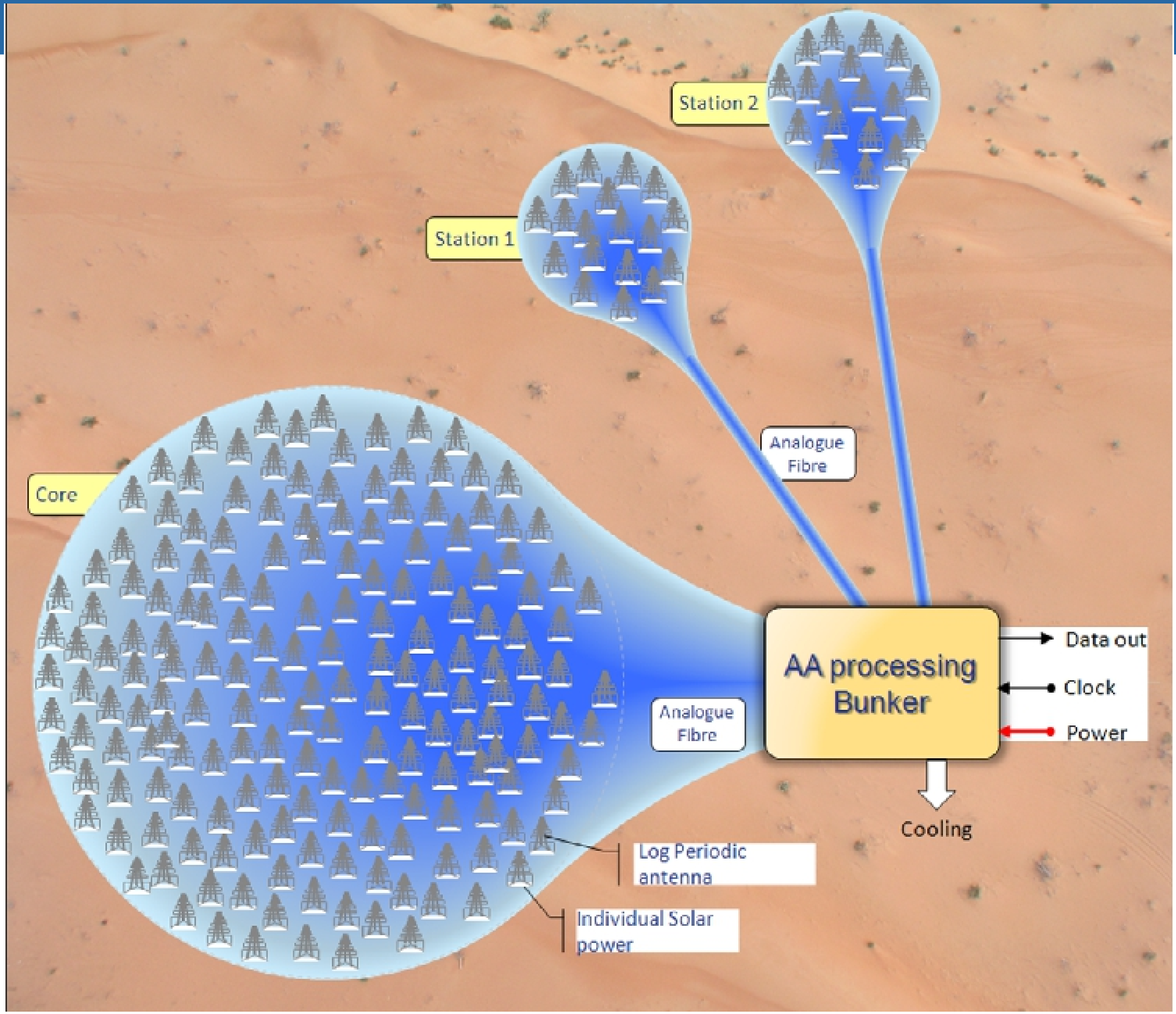
Some LFAA design choices made…

- Single antenna type
  - Cheaper
  - Baseline design has limited frequency range
- All beamforming in the digital domain
  - Precision
  - Analogue beamforming high cost
  - Flexibility
- Digitisation in the Bunker
  - RFI risk
  - Clock distribution challenge
  - Power distribution

Target Implementation

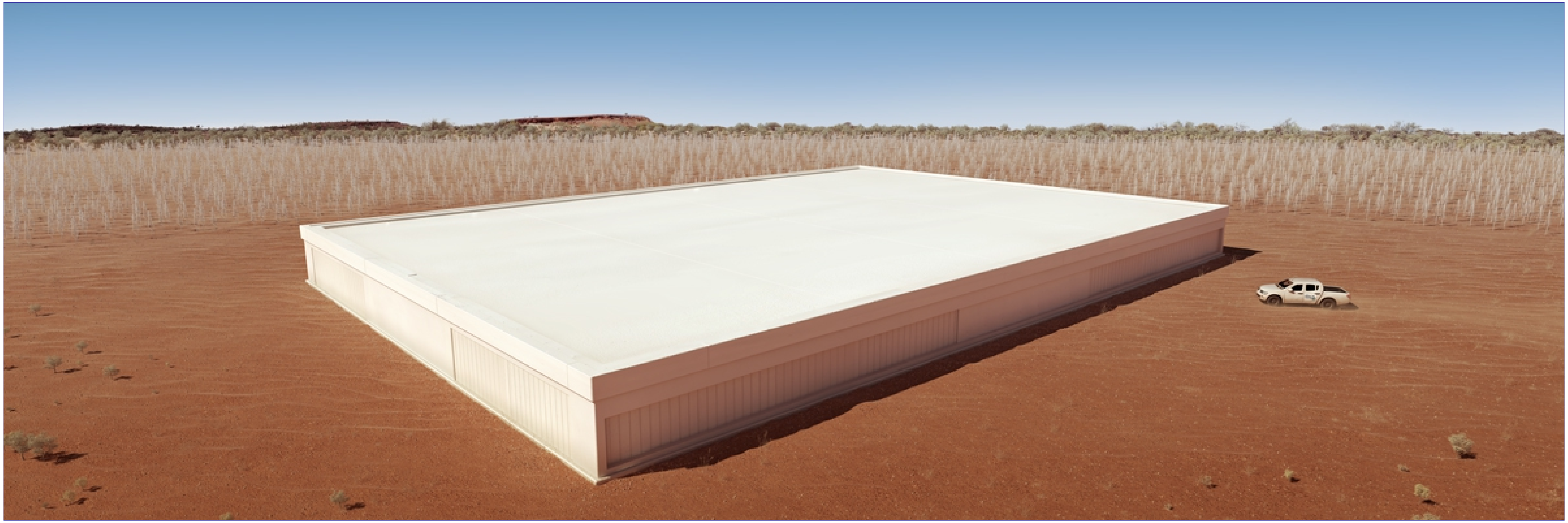
- Individual Log-periodic antennas – single array
- Analogue fibre signal transport from each antenna
- Individual solar power (+battery) at each antenna
- Single (large) processing Bunker (256 racks)
- Band selection using ADC baseband or first alias
- Data routing inside Bunker using COTS switches

Target Implementation: Single Bunker



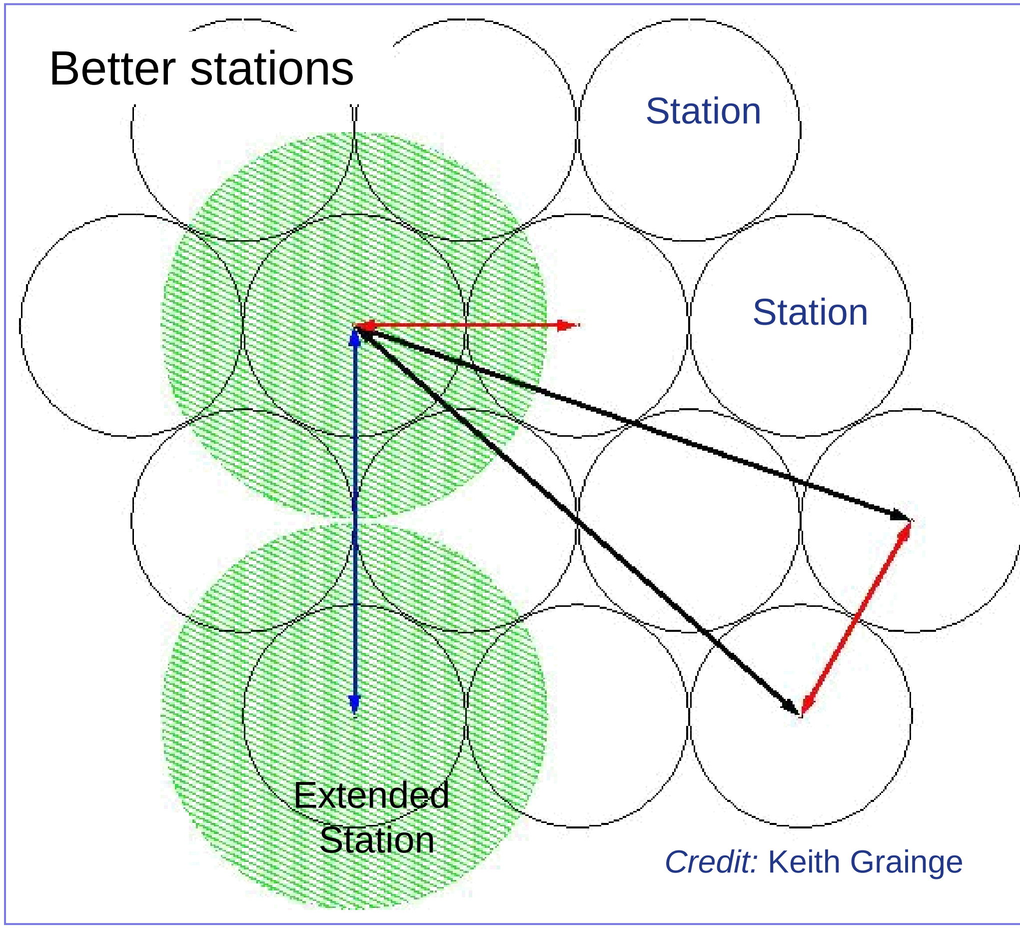
Technical overview

Antenna:	Log Periodic	*Signal transport:*	Analogue fibre
No. of ant.:	262,144 (2^{18})	*Processing:*	Digital
Ant. spacing:	1.5m – 2.0m	*ADC res.:*	8-bit (ENOB 6.5?)
Station size:	256 ant. ~35m dia.	*Tiles:*	16 antenna per "Tile"
		Data routing:	Switch network
No. of stations:	1024		



Capabilities of the design…

No. of stations:	1024 *or* 512 *or* 256
Station dia,:	35m *or* 50m *or* 70m
Multiple Beams:	Flexibly allocated in available data rate
Beam forming:	Improved apodisation
Scan angle:	60° max.
No. of Bands:	2
Frequency Ranges:	50MHz – 375MHz 375MHz – ≤650MHz
Data rate:	≥10Tb/s



Credit: Keith Grainge

REDUCING SKA1 system cost and/or
IMPROVING performance….

Worries…

- System software:
  - System control
  - Telescope manager interface
  - Calibration
  - Test environment e.g. for AAVS1
- Network management
  - Steering data
  - Network management tool
- Calibration algorithm and implementation
  - AAVS1…

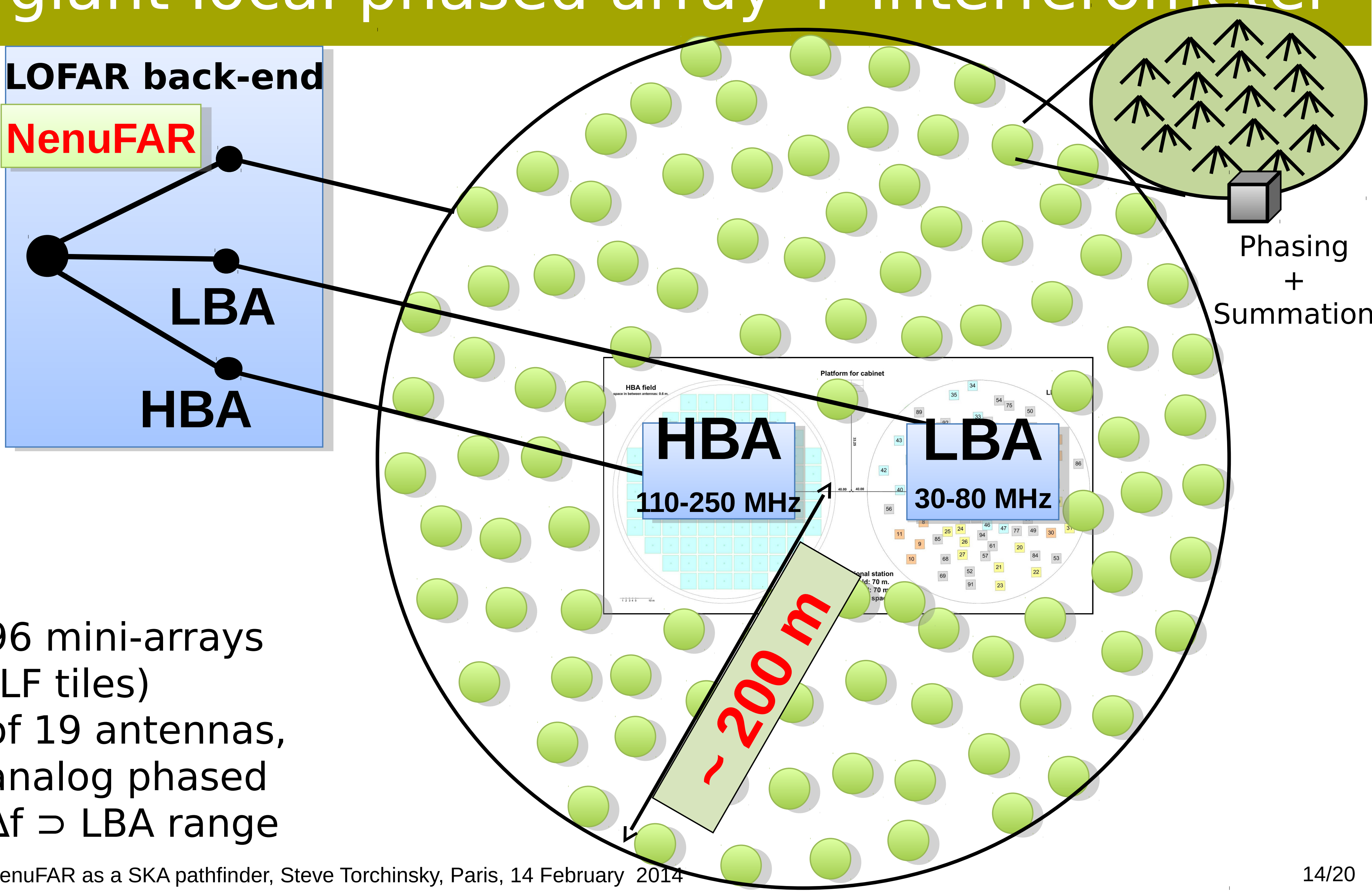
SKA1-Low: Need to fully prove

- RF over Fibre capabilities
  - Range
  - Phase Stability
  - Power
  - Cost
- Stability of station beams
- Calibrateability of the arrays
- Beam performance for imaging
- Deployment approach and time for antennas

SKA1-Low: some noteworthy points

- nearly 300 000 log periodic dipoles
- no analog beamforming. digitization in a central bunker for the whole system.
- beamforming organized by station, as with LOFAR, but the station size is selectable. This gives freedom to configure the size of the FoV
- lowest frequency: 50MHz. NenuFAR could possibly make an important contribution by demonstrating the importance of lower frequency.

The LSS/NenuFAR concept : giant local phased array + interferometer



96 mini-arrays
(LF tiles)
of 19 antennas,
analog phased
Δf ⊃ LBA range

[NenuFAR - 1](https://nenufar.obs-nancay.fr)

https://nenufar.obs-nancay.fr

Technical characteristics of NenuFAR-1

- Number of antennas : 285 (15 mini-arrays of 19 antennas),
  within an ellipse ~110 m x ~ 140 m Frequency range : ~10-85 MHz (also the bandwidth per beam) Resolutions : down to δf = 3 kHz and δt = 5 μsec (δf x δt ≥1) Waveform snapshots capture mode at 5 nsec resolution (TBB) Polarizations : 2 linear antenna (NW-SE & SW-NE) → 4 Stokes computed Pointing declination : -23° to +90° (Nançay latitude = 47.38° N) Effective area : $\lambda^2/3$ per antenna, ~95λ^2 for NenuFAR-1
- (≤ 10^4 m^2 due to overlapping Aeff ≤30 MHz) FoV : antenna ~2π sr, phased mini-array 34°–9° at 20–80 MHz Number of beams : 2 (full band, 70 MHz) Angular resolution / pencil beam size : 7°–2° per beam at 20–80 MHz Sensitivity S_{min} : 12-3 Jy at 20–80 MHz (5σ, 1 secx10 MHz, polarized signal) 55–200 mJy at 20–80 MHz (5σ, 1 hx10 MHz, polarized signal) Confusion noise at zenith : 400–10 Jy at 20–80 MHz (140 m diameter)

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LOFAR is an SKA Pathfinder

- Key science
- Technology
  - Signal processing (beamforming etc)
  - Calibration
  - Array configuration

NenuFAR as a SKA Pathfinder

- NenuFAR should make a case independent of LOFAR that it is a SKA Pathfinder

NenuFAR
Pathfinder for SKA

- How to deal with confusion limit for contiuum imaging
- experience with multi-mode observing and sub-arraying
- array configuration including polarization distribution of tiles
- calibration
- experience with trenching and cabling configuration
- science pathfinding:
  - Importance of lower frequency limit
  - science objectives of LSS will provide input to observational strategies, detections/non-detections will inform technical requirements, etc
- sub array methodology (especially important with SKA-low selectable station size)
- multiple FoV
- RFoF?

These arguments would carry a bit more weight if we were directly involved in SKA-Low development so that we'd have the natural communication line to SKA.

Question

- Why do we want NenuFAR to be considered a SKA Pathfinder?

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