

An aerial photograph of the SKA radio telescope array in a desert landscape. The image shows numerous large, circular, white, stepped structures (antennae) arranged in a grid-like pattern across a vast, arid, reddish-brown plain. In the foreground, a small white car is parked next to one of the larger structures, providing a sense of scale. The background features distant, hazy mountains under a clear blue sky.

# SKA AA Power Challenges

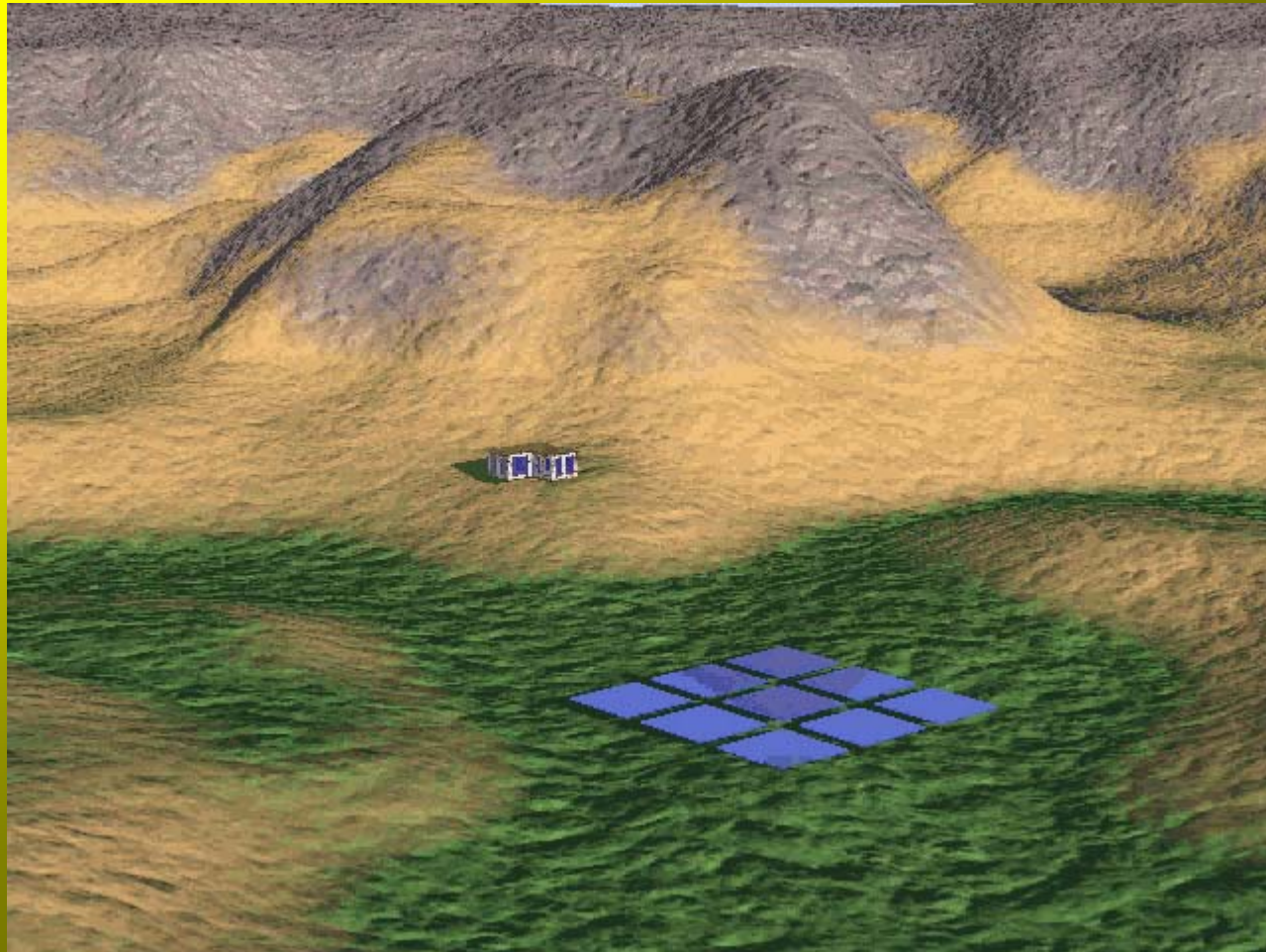
Andrew Faulkner



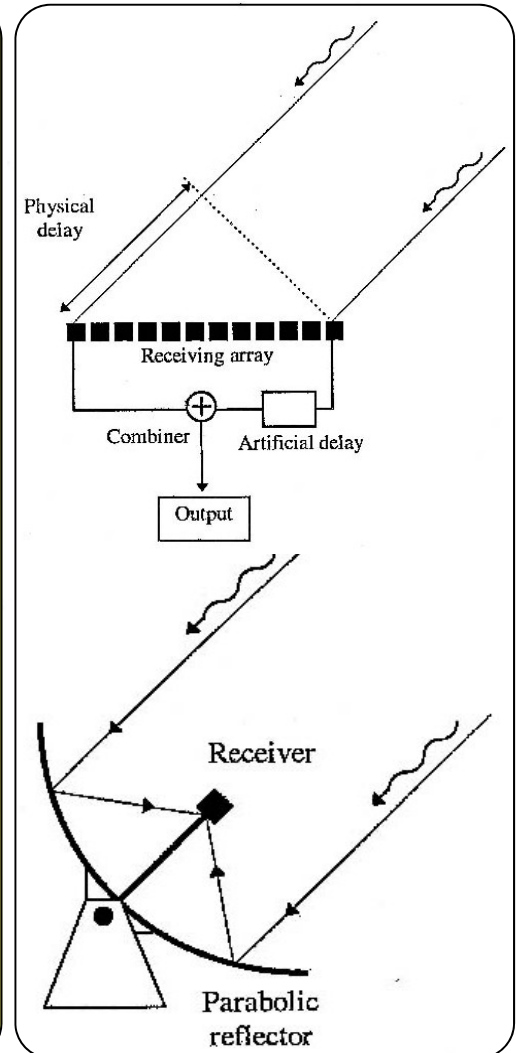


What is the AA Power  
challenge...?

....an awful lot of “stuff”!

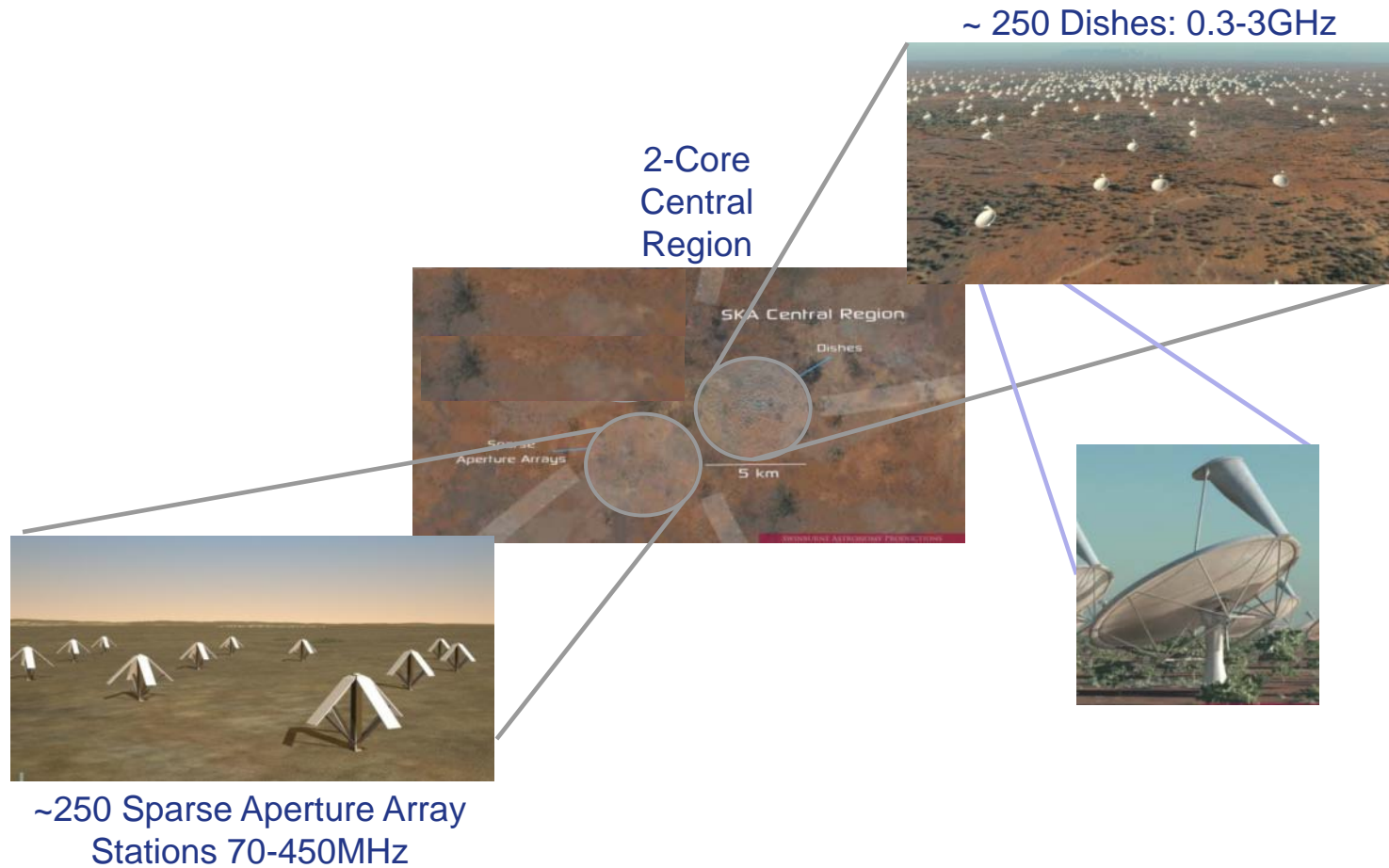


Michael Kramer





# SKA<sub>1</sub> construction: 2016-2019

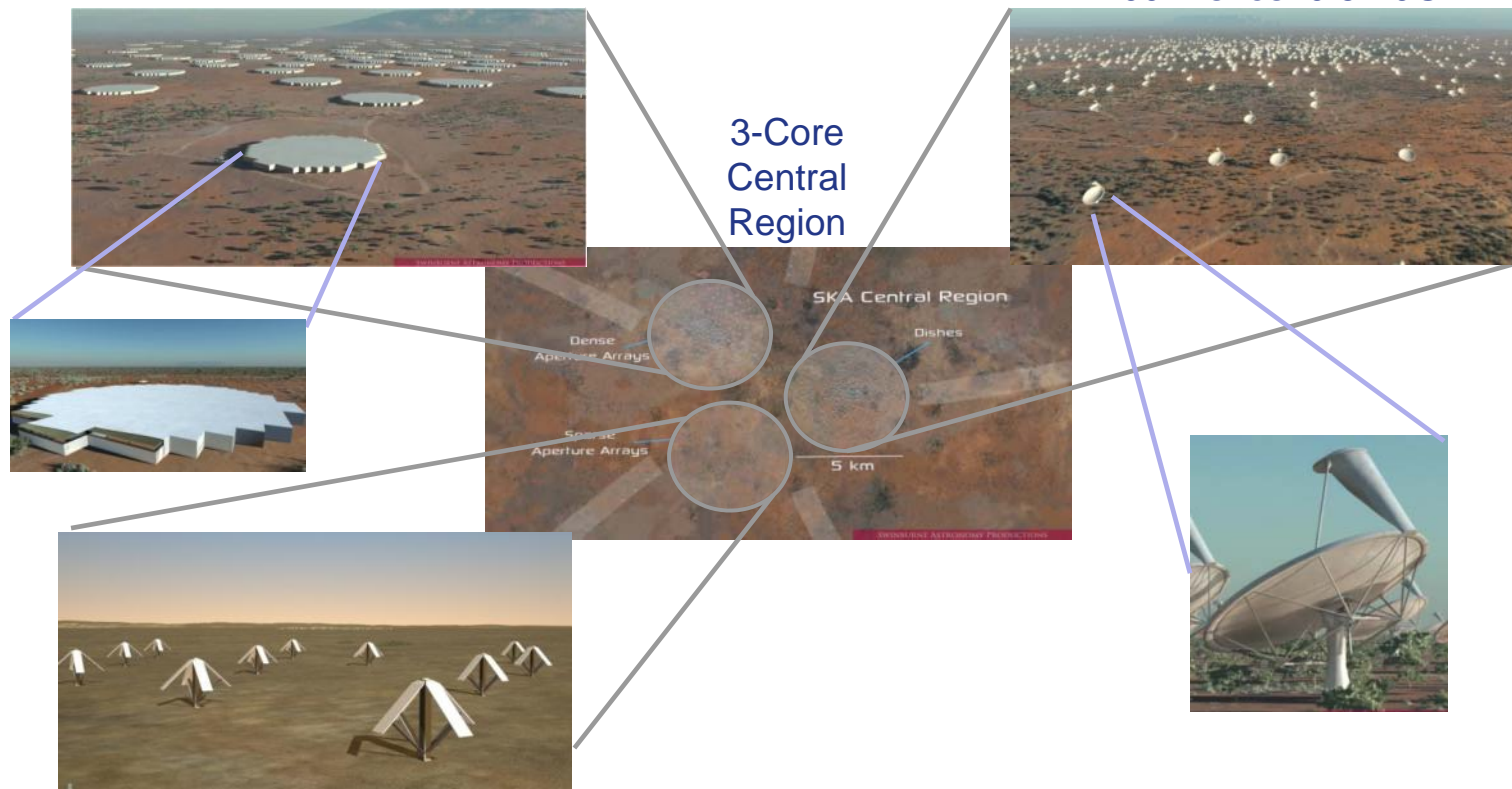


*Artist renditions from Swinburne Astronomy Productions*

# SKA<sub>2</sub> construction: 2020 on

~ 250 Dense Aperture Array  
Stations 400-1450MHz

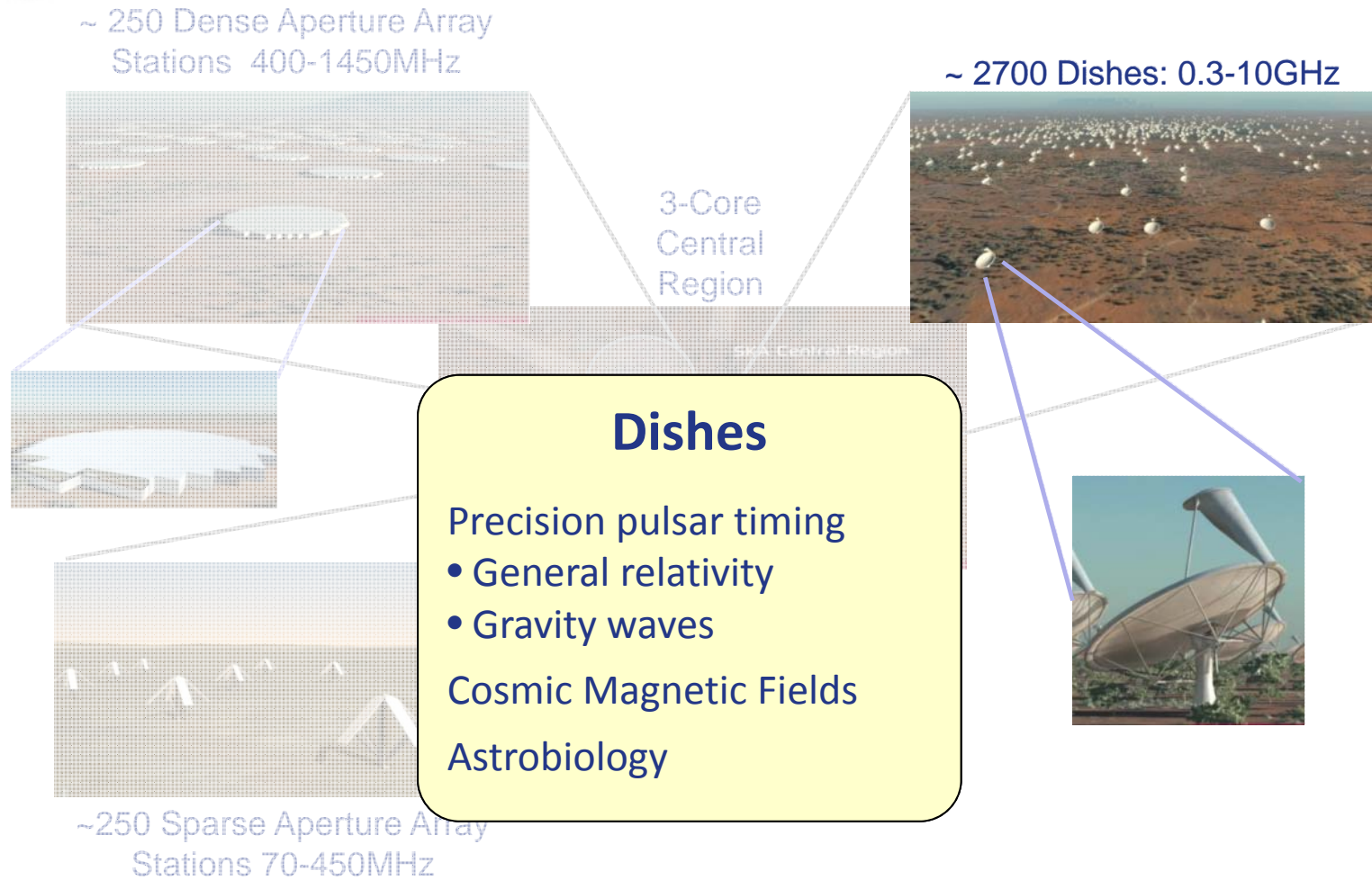
~ 2700 Dishes: 0.3-10GHz



~250 Sparse Aperture Array  
Stations 70-450MHz

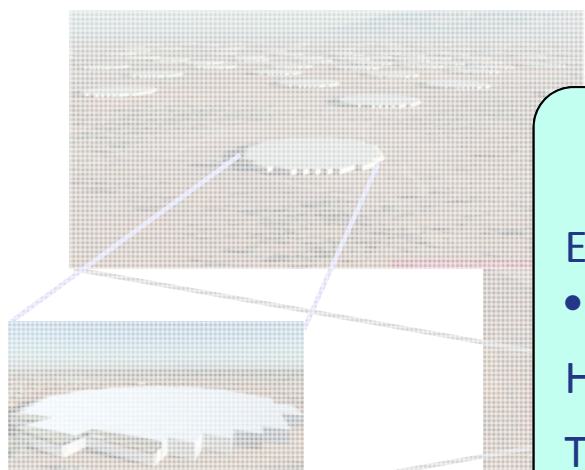
*Artist renditions from Swinburne Astronomy Productions*

# Some SKA Experiments.....



## Some SKA Experiments.....

~ 250 Dense Aperture Array  
Stations 400-1450MHz

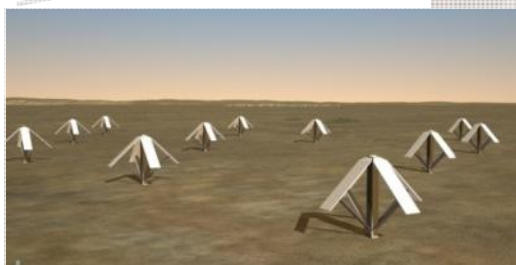


~ 2700 Dishes: 0.3-10GHz



### AA-low

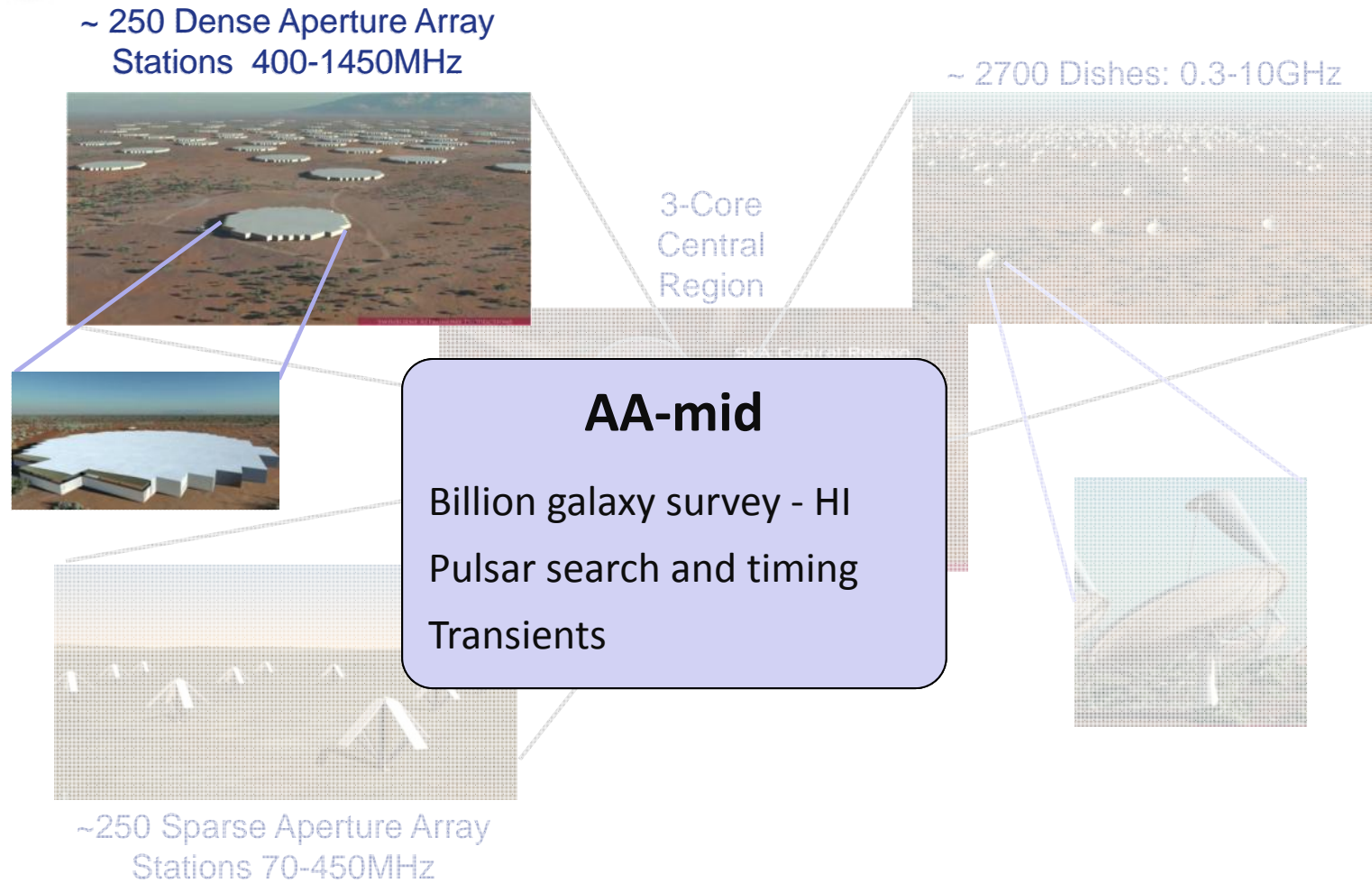
Epoch of Re-ionisation  
• Birth of the Universe  
HI absorption  
Transients



~250 Sparse Aperture Array  
Stations 70-450MHz



## Some SKA Experiments.....





## Sensitivity Comparison

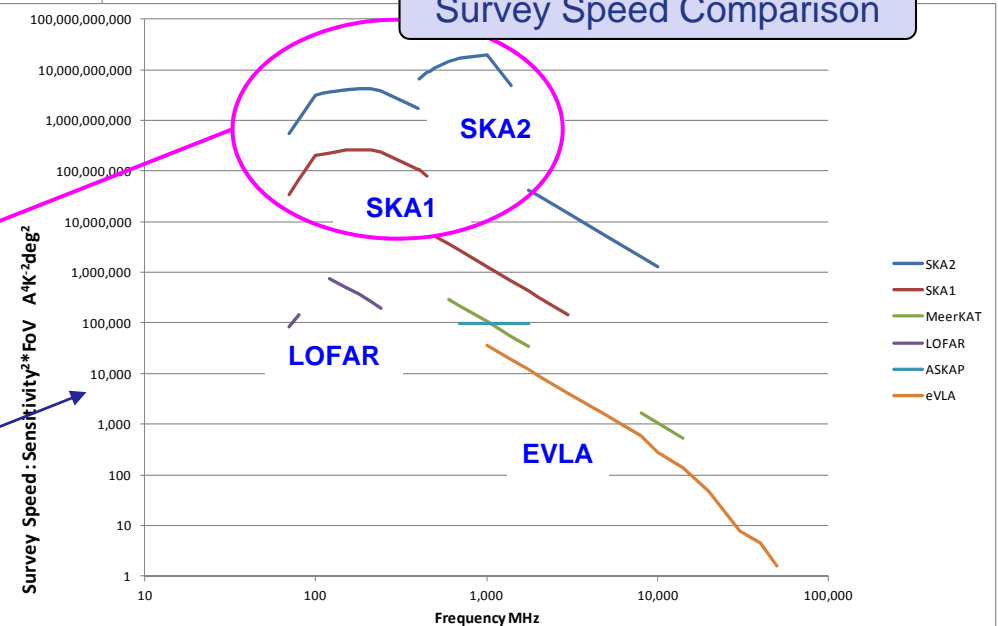


SKA<sub>1</sub> & SKA<sub>2</sub> will have much higher sensitivity & survey speed than existing instruments

Aperture Arrays

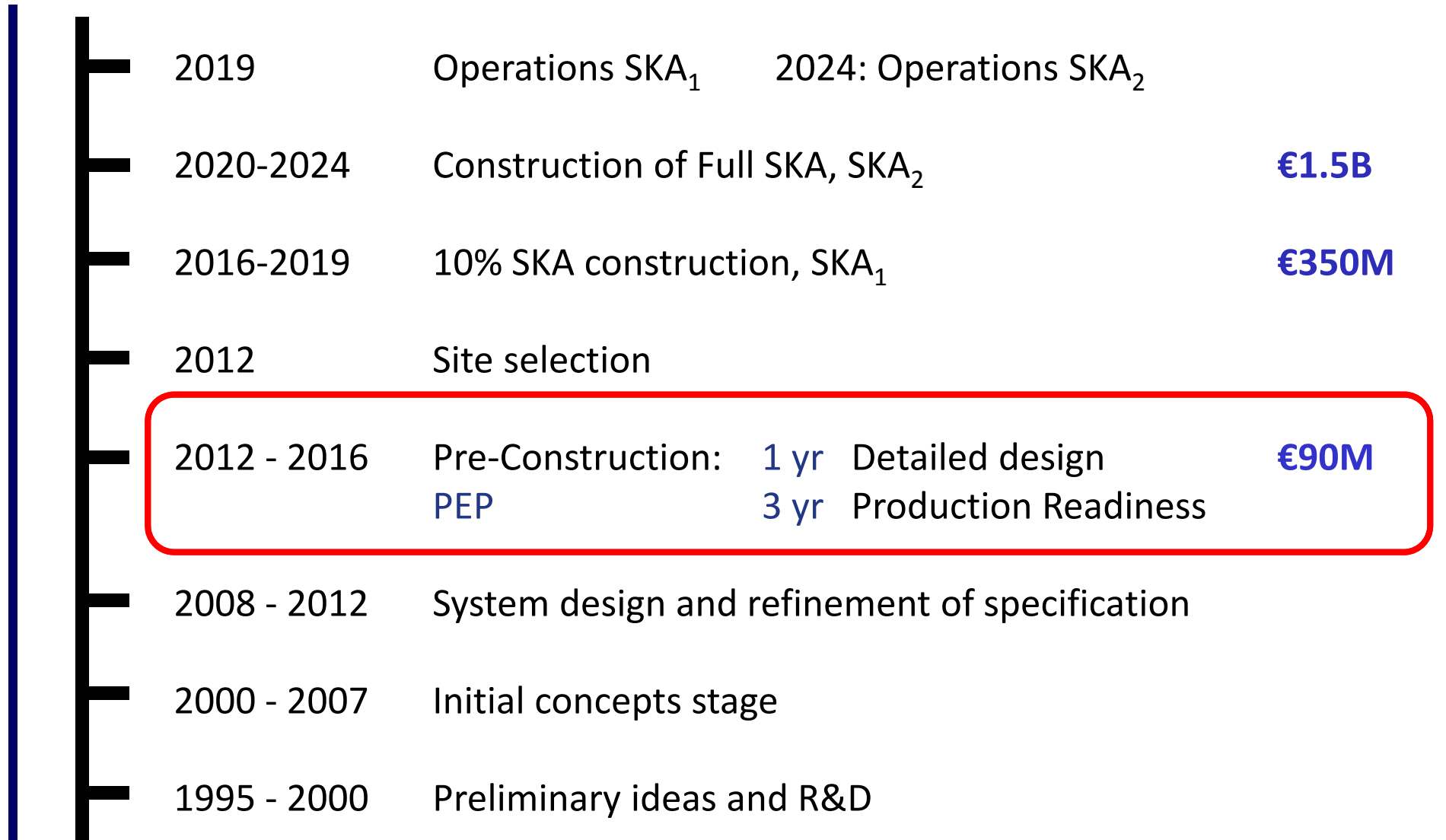
Note: log scale!

## Survey Speed Comparison





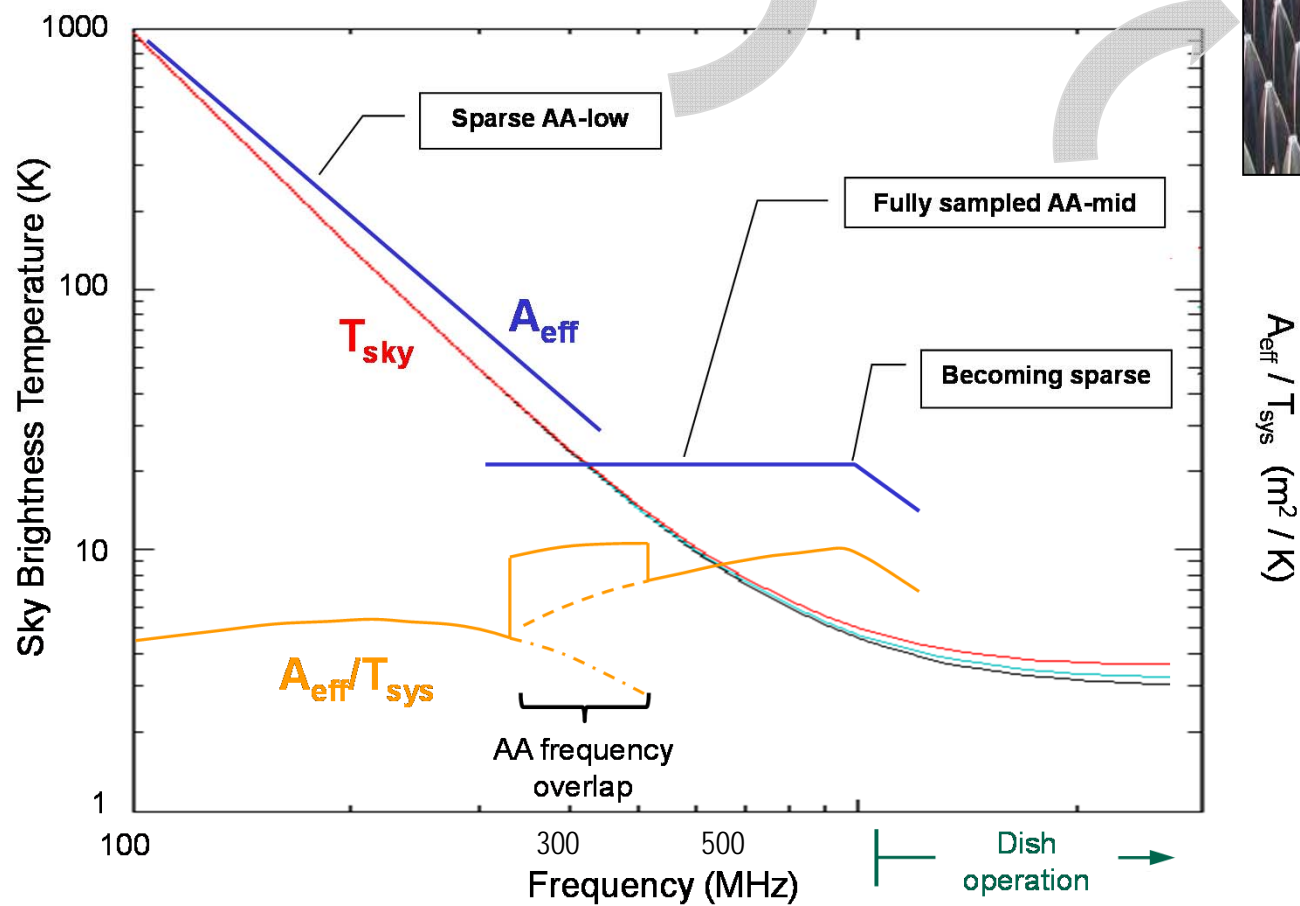
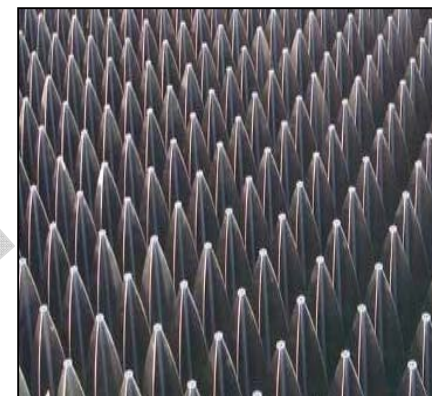
## SKA Timeline



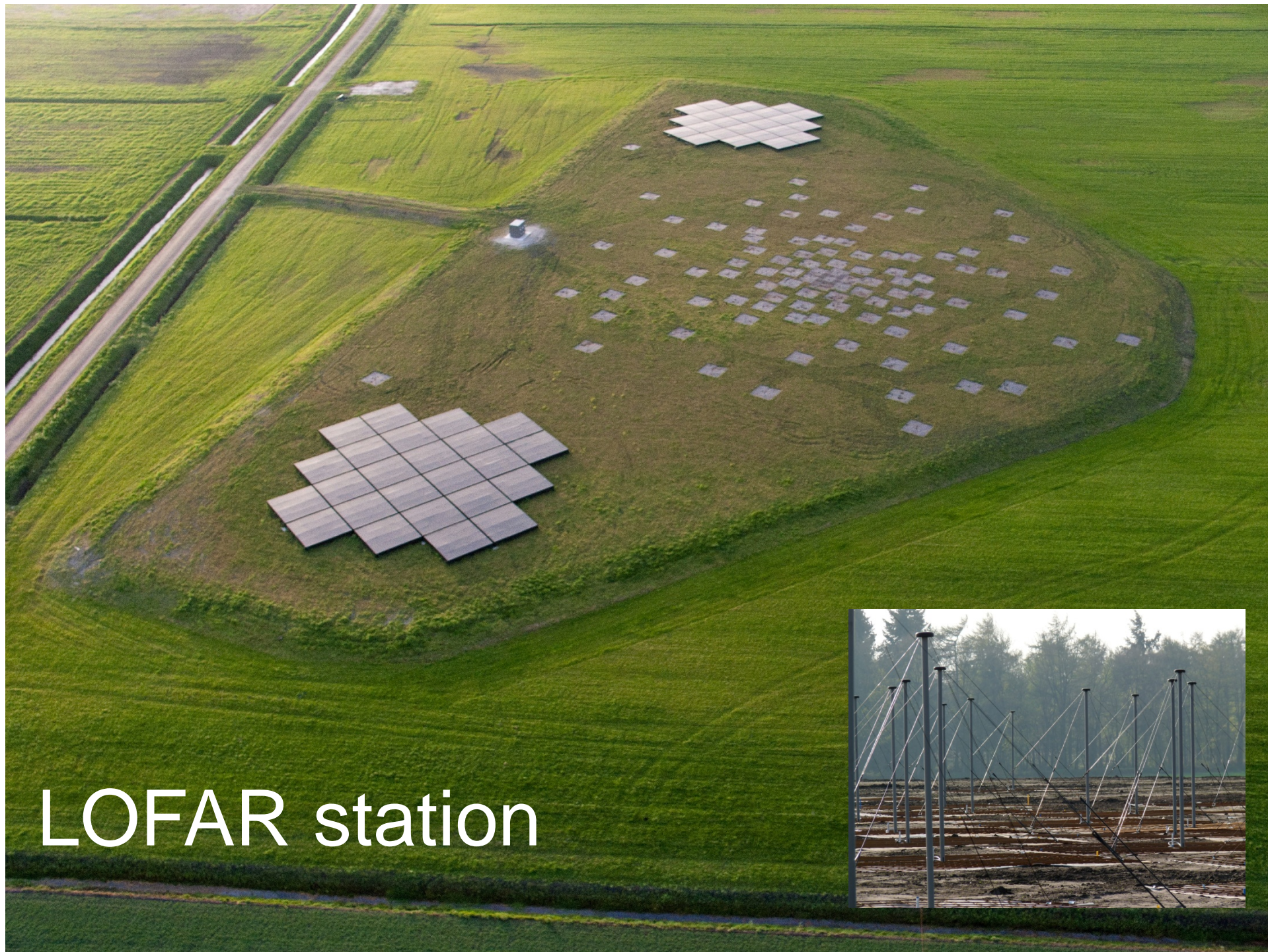




## Type of AA selection





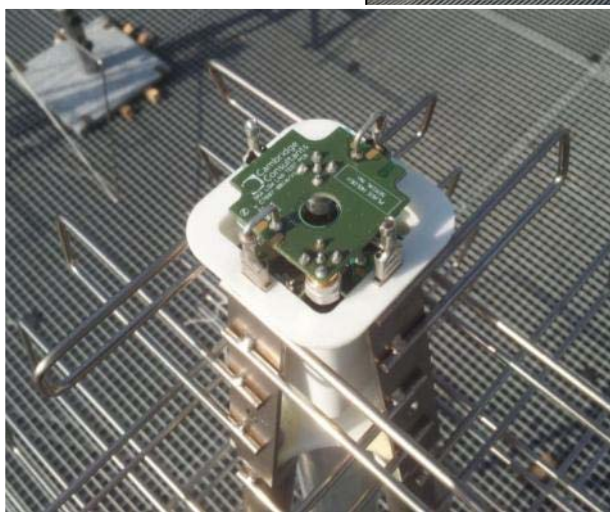
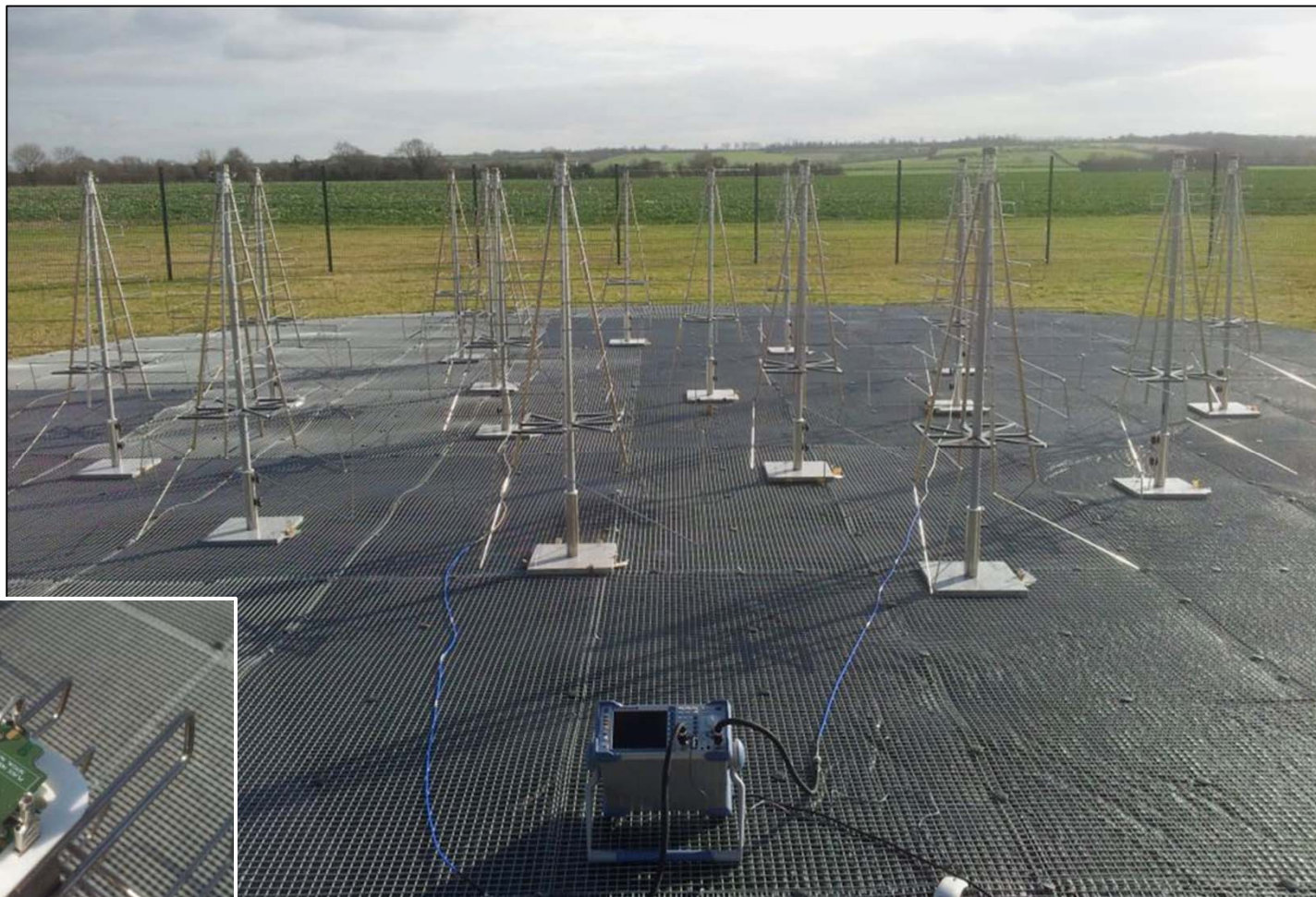


LOFAR station





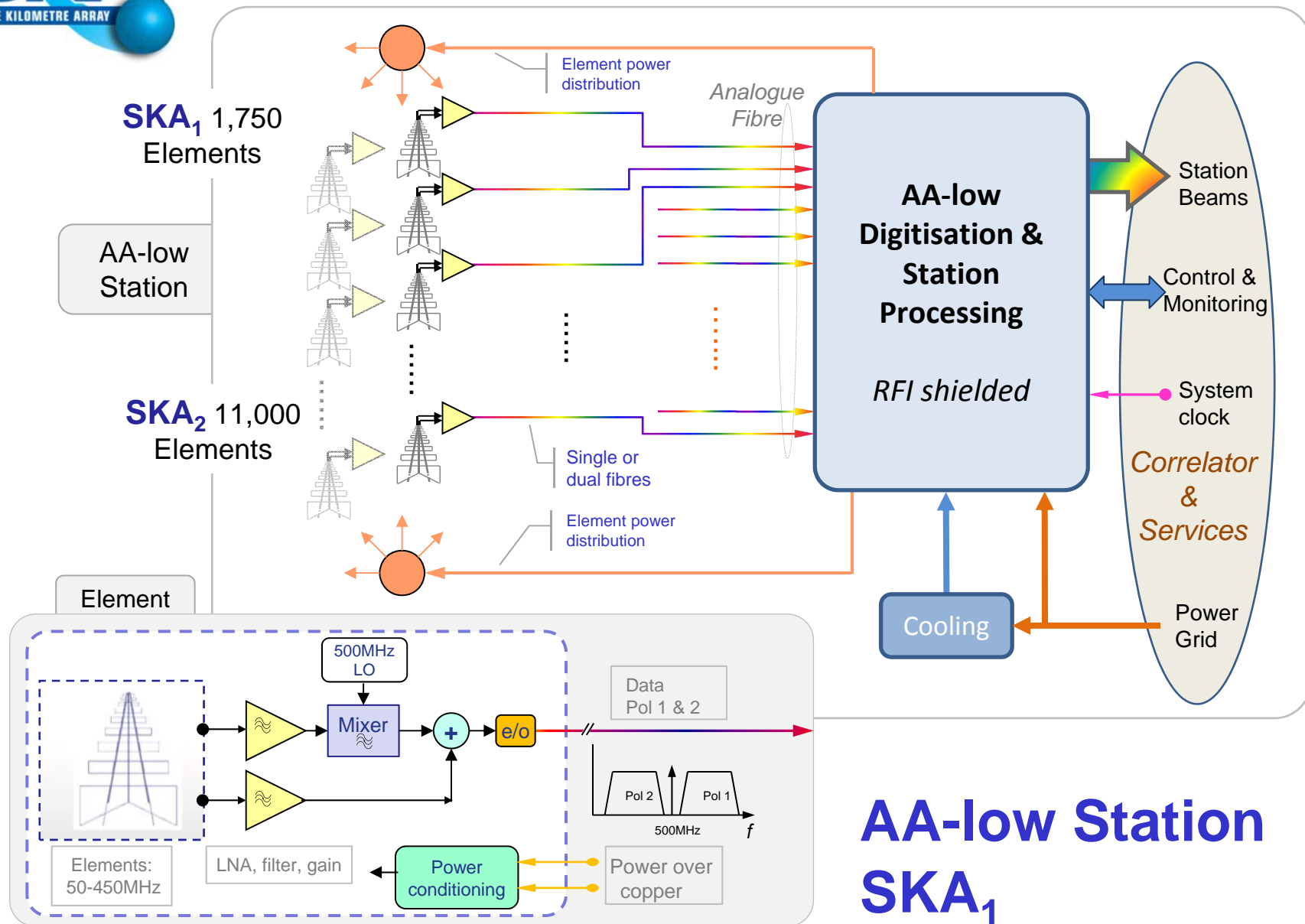
## AA-low – Development



# AA-low outline specification

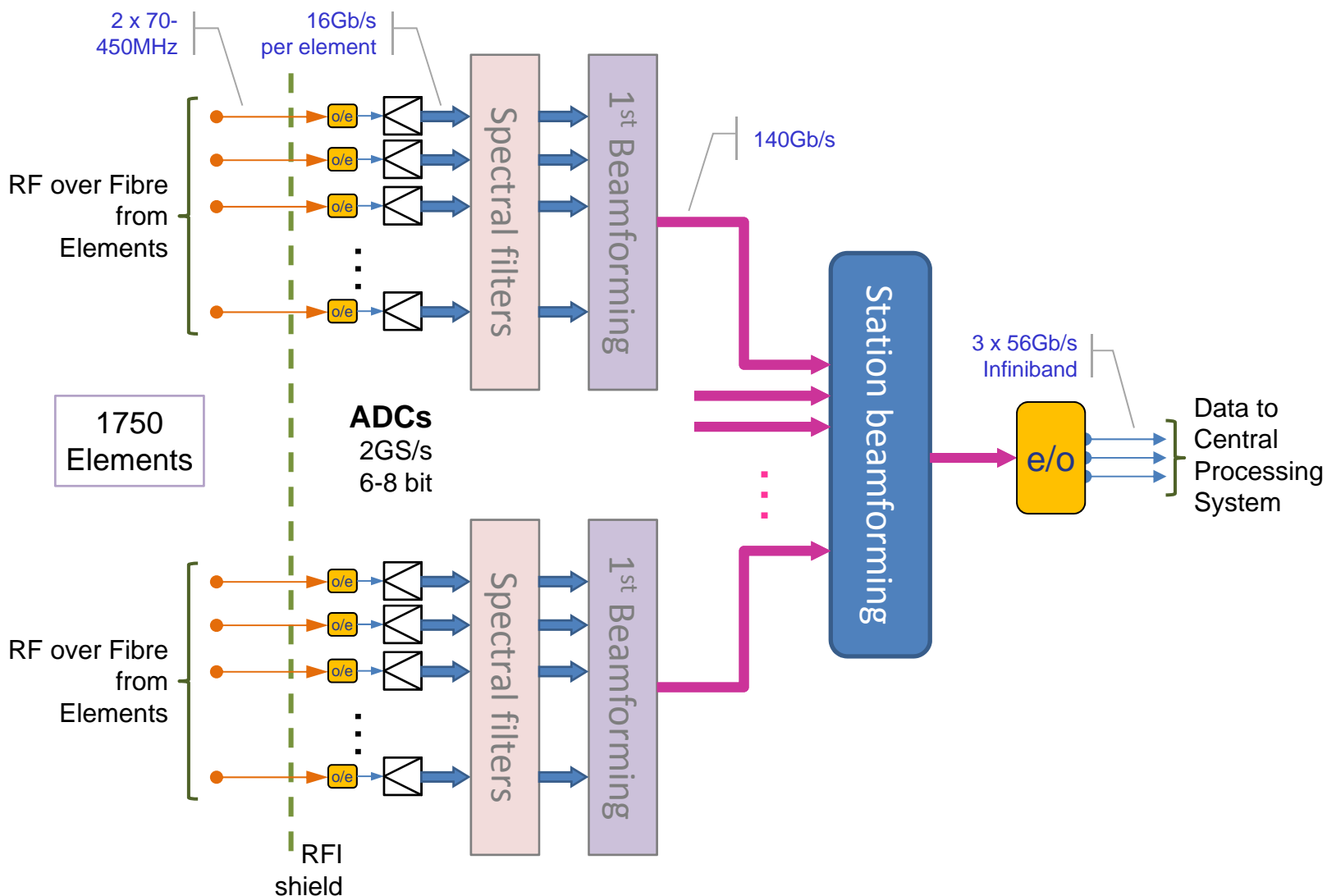
Parameter	SKA1	SKA2	Comments
Type of array	Single element	Single element	Sparse array using a single wide-band element
No. of elements /station	1750	11,000	
No. of elements total	500,000	3,000,000	Approximately
Approx. Size of elements	1x1x2 m	1x1x2 m	Must be small enough for the pitch
No. of polarisations	2	2	Each element has two receiver chains
Diameter of station	80m	180m	
Number of stations	280	280	Anticipated number SKA Stations
Element communication	Analogue fibre	Analogue fibre	Requires copper for power
Layout	pseudo-random	pseudo-random	The most flexible design is as individual elements.
Frequency range	70-450 MHz	70-450 MHz	May be down to 50MHz
Digitisation rate	1 - 2GS/s	1 - 2GS/s	There is no frequency conversion, covers full frequency range with guard bands
Digitisation depth	6 or 8-bit	6 or 8-bit	Required for RFI environment at these frequencies
Max instantaneous bandwidth	400 MHz	400 MHz	Covers operating band of array
Output data rate /station	140Gb/s	8Tb/s	Organised as 4+4bit complex data
Data rate into correlator	40Tb/s	2.2Pb/s	Peta = $10^{15}$





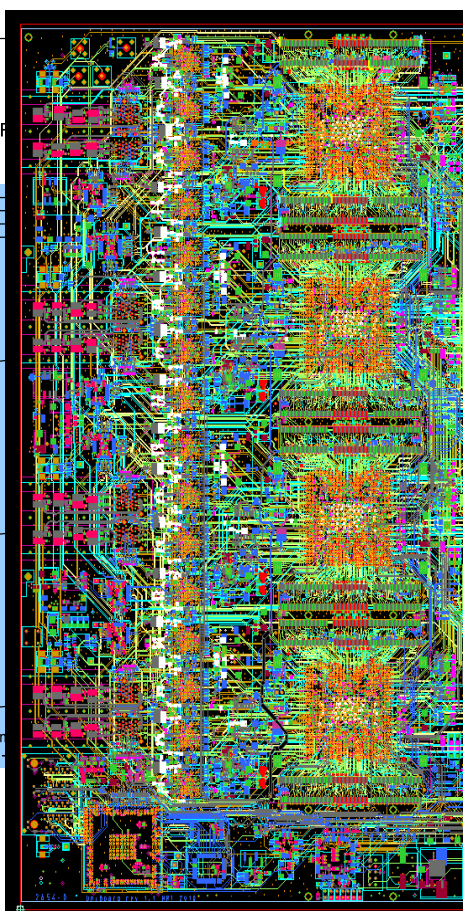
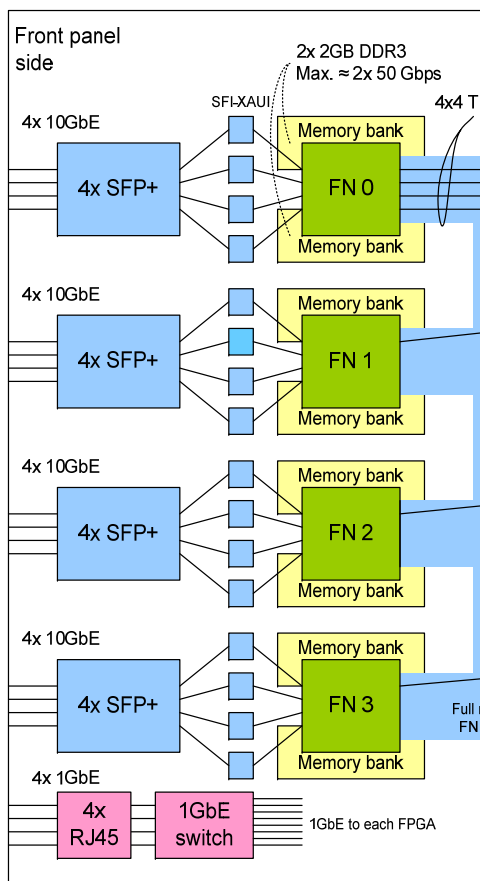
## AA-low Station SKA<sub>1</sub>

# SKA<sub>1</sub> AA-low Station Processing



# Uniboard 1 (Jive)

- 16 input signal paths
- Input bandwidth: 450 MHz, digitised
- Output bandwidth: 40 beams of 300 MHz
- 14 layer board; Altera Stratix 4 230: 500 GMAC/s

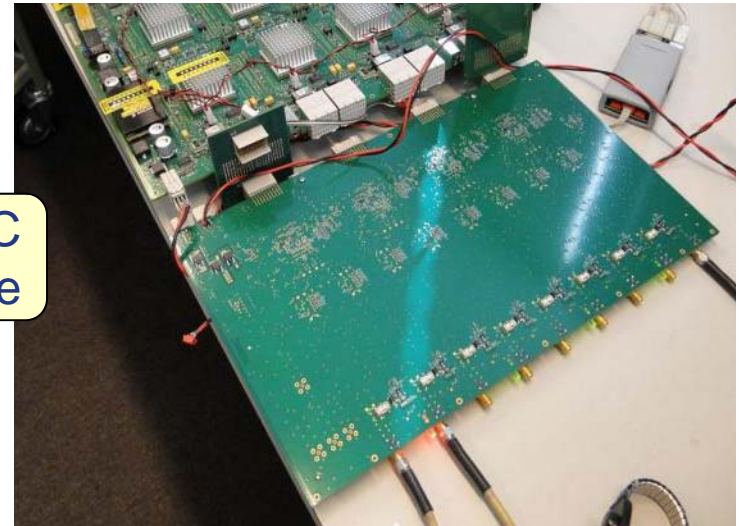




# Uniboard 1 Implementation

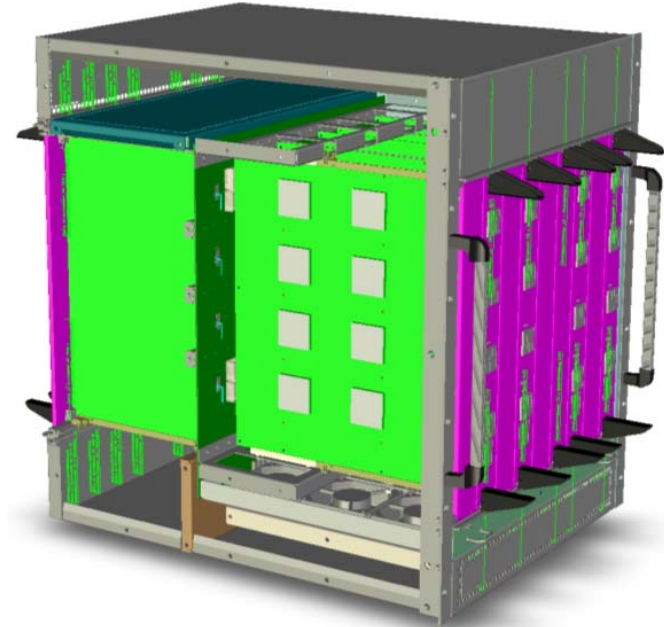
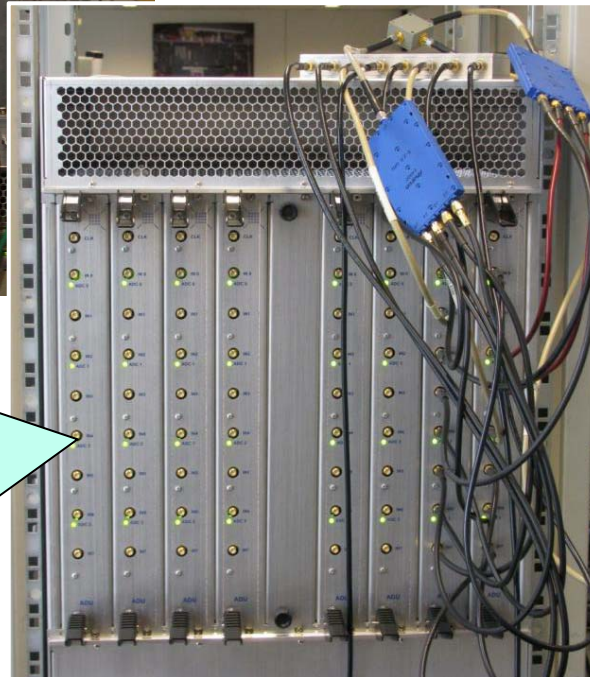


ADC  
Interface



## Shelf:

- 4 Processors
- 8 ADC interfaces
- 64 inputs  
(32 elements)



# AA-low SKA<sub>1</sub> Station power

Total AA-low station power ~10kW **3MW** tot

## Processing and digitisation

Technology	FPGA (TMAC/s)	Board (TMAC/s)	# per station*	Power/Board, inc ADC (W)	Total
UNIBOARD 1	0.5	4	200	400	80kW
UNIBOARD 2	~4.0	32	25	500	12.5kW
SKA1 processing	10 est.	80	10	700	<b>7kW</b>

\*allowance made for inefficiency

## Processing requirement

### Spectral filter:

Polyphase filter into 1024 channels	$10^5$ MACs	
PFF rate at 1GS/s	$10^6$ /s	
Processing rate per element	$2 \times 10^{11}$ MAC/s	
Total spectral filter proc. (1750 el.)	$3.5 \times 10^{14} =$	350TMAC/s

### Beamforming:

Each element 40GS/s (>160Gb/s):	$8 \times 10^{10}$ MAC/s	
Total processing/station (1750 el.):	$1.4 \times 10^{14} =$	140TMACs

Total station processing: **~500TMAC/s**

## Analogue and Comms Power

### Element power

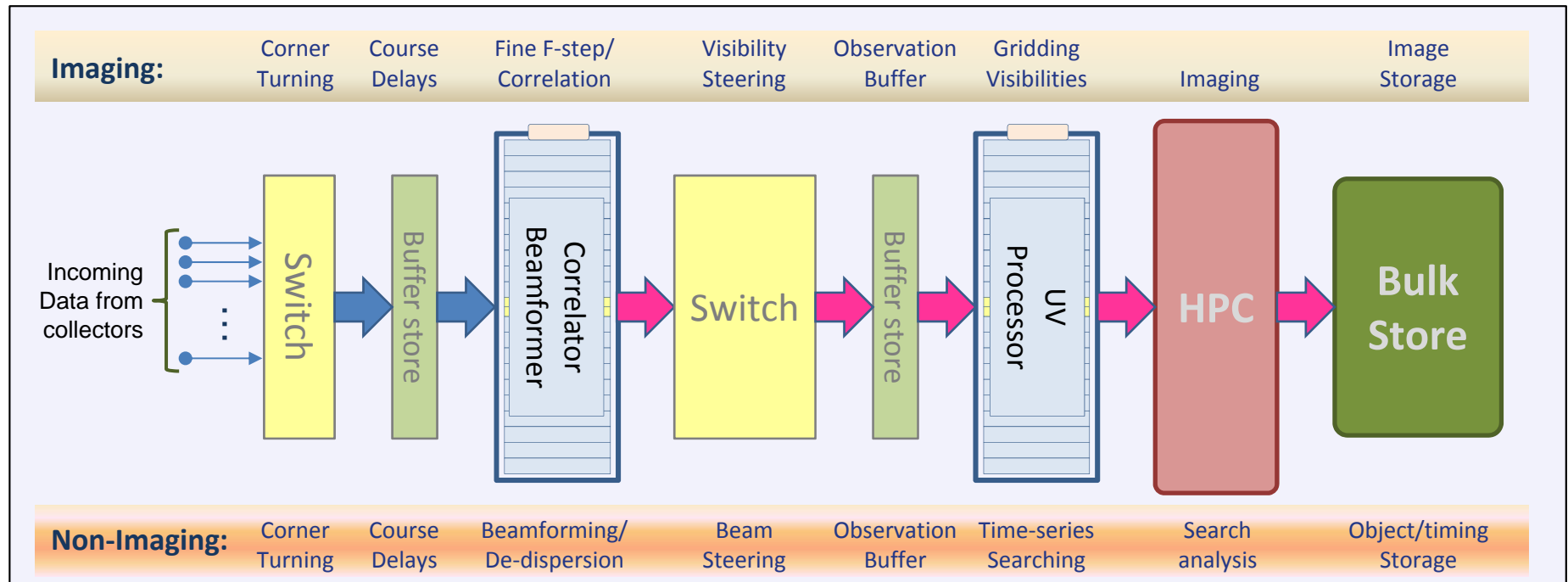
LNA	50mW	100mW
Gain chain and mux	50mW	100mW
Optical Transmission	100mw	150mW
Total Element power		350mW
All elements		<b>&lt;1000W</b>

### Communications etc. power

Transmission 3*56Gb/s	100W
Internal comms 30*56Gb/s	300W
Misc.	1000W

Total Station **2.5kW**

# Central processing pipelines



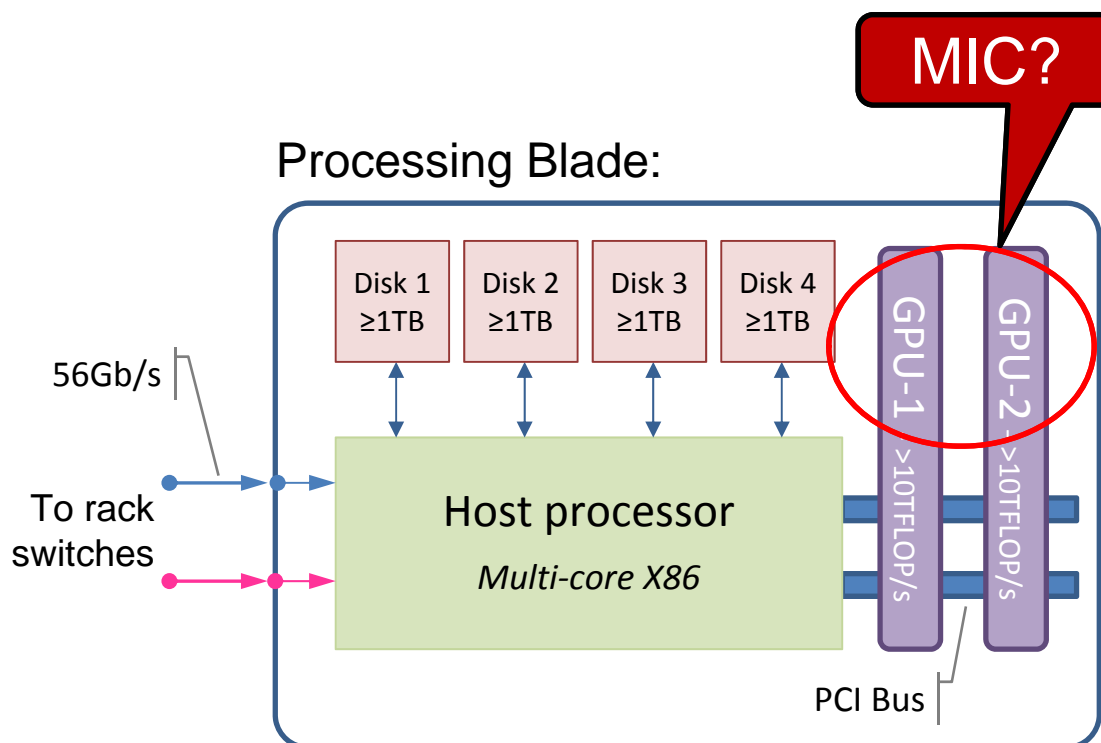
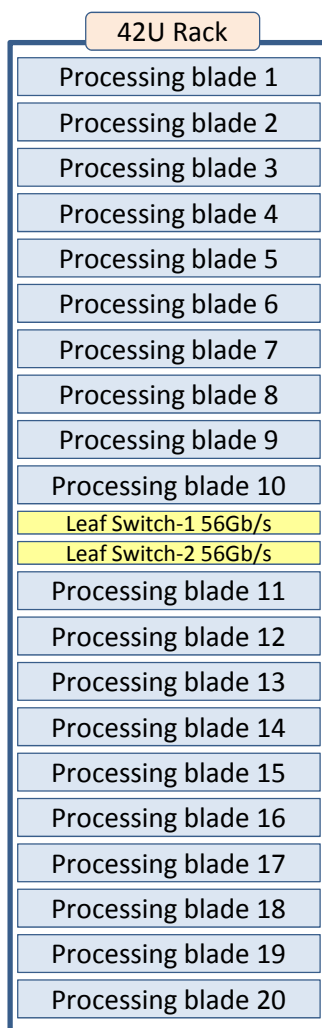
## Functions:

Correlator, beamformer, gridding, imaging, searching, timing & storage

**Flexible, upgradeable, development path**

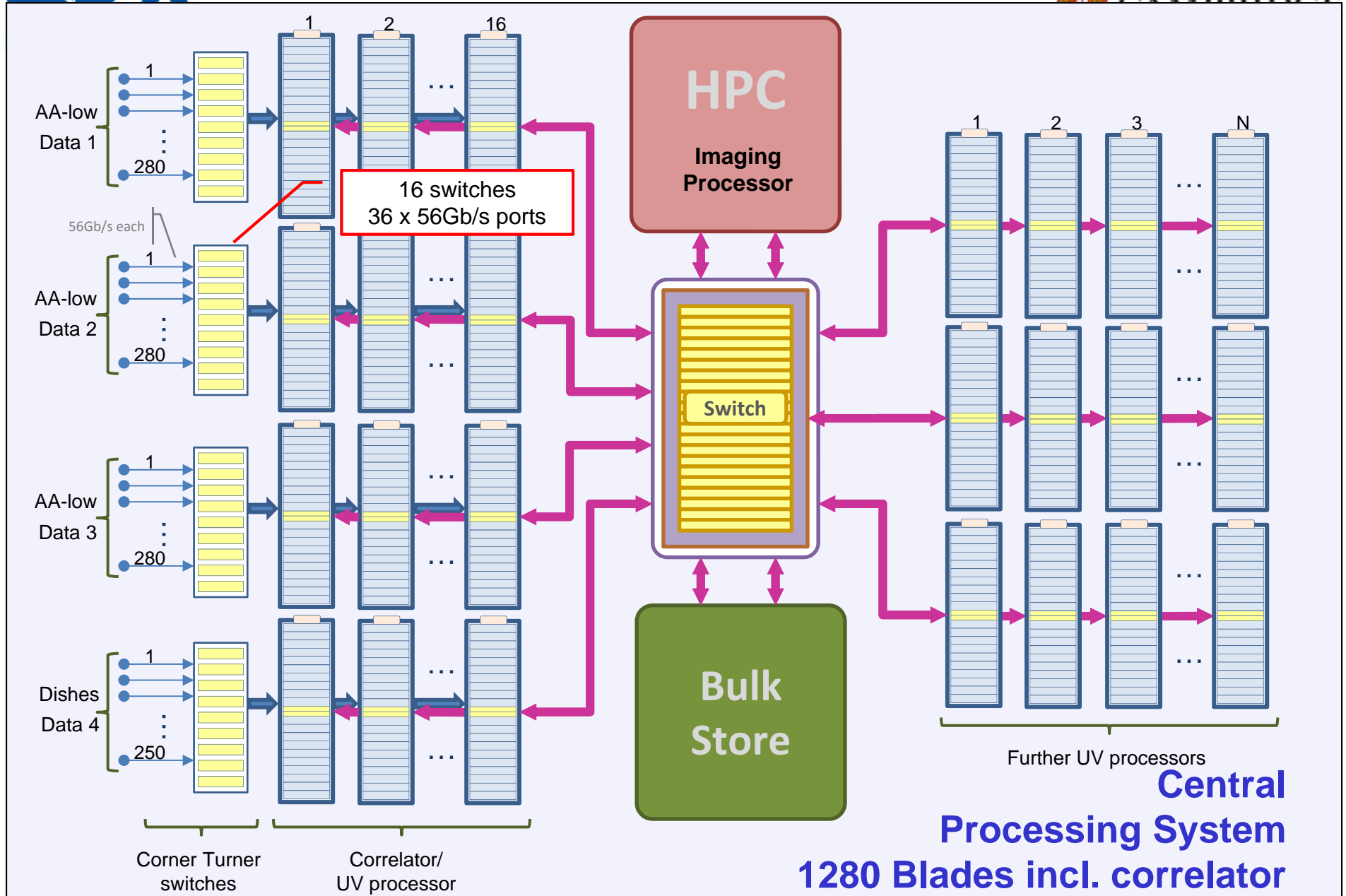


# Processing rack and blade



## Blade Specification

- 20 TFlop
- 2x56 Gb/s comms
- 4 TB storage
- <1kW power
- Capable host (dual Xeon)
- Programmable
- Significant RAM



# Central processing power

	Racks	Power kW		Comments
		/rack	Total	
Corner turning switches	2	7	14	Houses both AA and Dish input switches
Correlator/UV processor	48	31	1488	Correlator with UV processing capacity
UV processor per 64GB/s	16	31	496	Number of UV processors to support 64GB/s of visibilities
Central switch	1	10	10	Occupies 29U, but expect rest will be filled with something
Imaging processor per PFLOP/s	5	80	400	Assumes BG/Q, more processing scales linearly
Bulk store with 4.3PB	3	20	60	1.5PB/rack expansion
<b>Total for Basic system</b>	<b>75</b>		<b>2,468</b>	<b>kW</b>

Includes AA-low & dishes



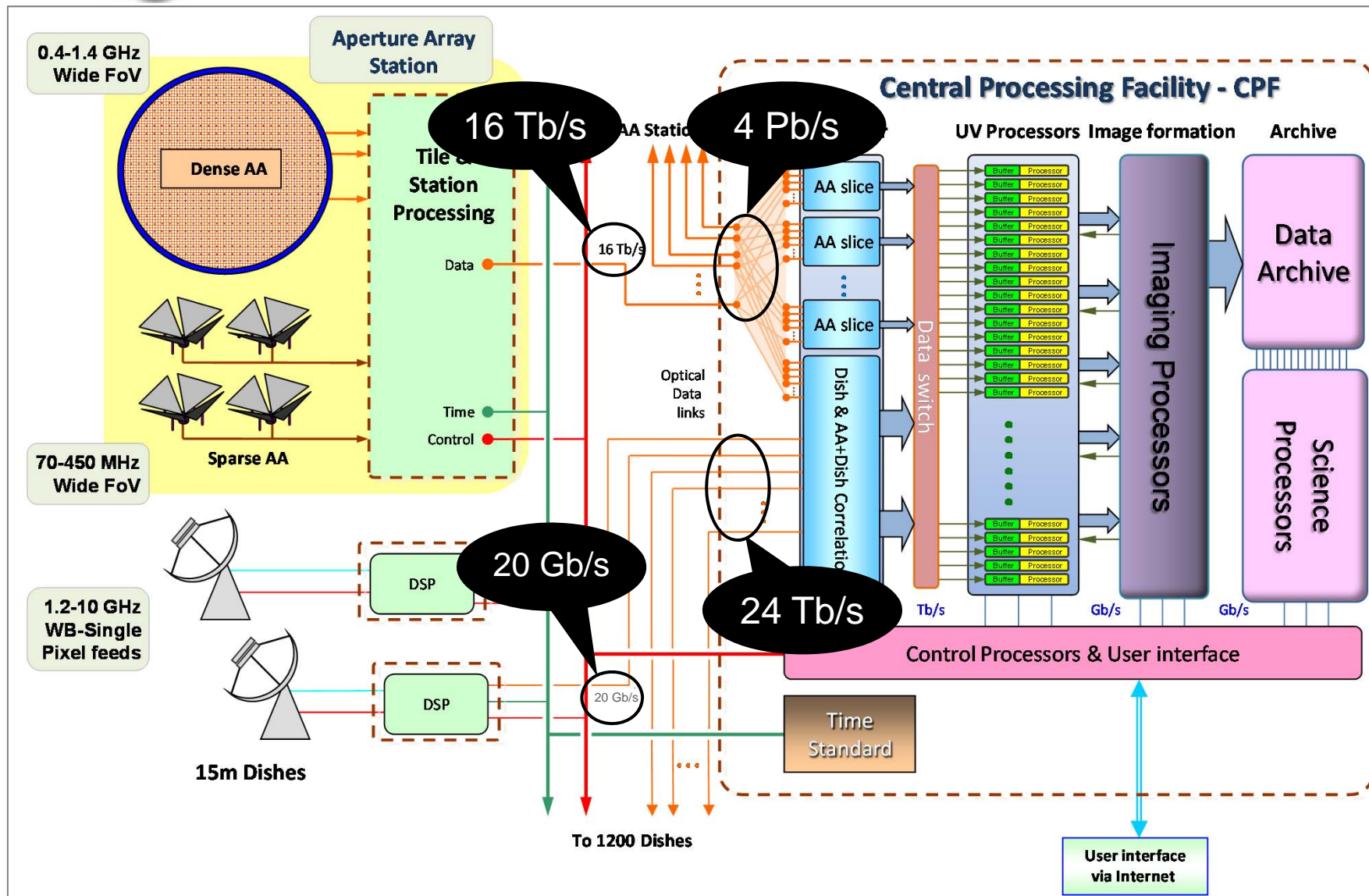
100MW !

## SKA Phase 2.....

### Challenges:

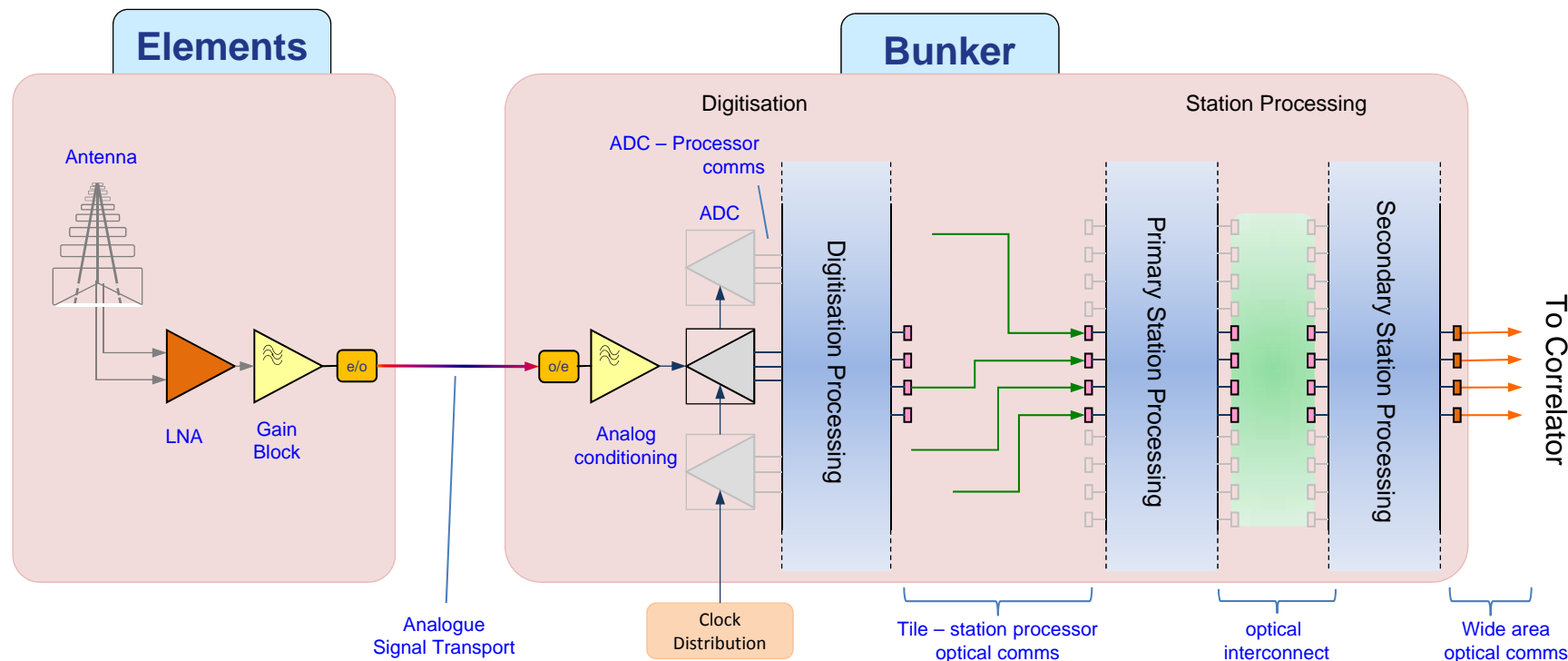
- Very high data rates
- Large numbers of elements
- Substantial processing requirements

# SKA<sub>2</sub> wide area data flow



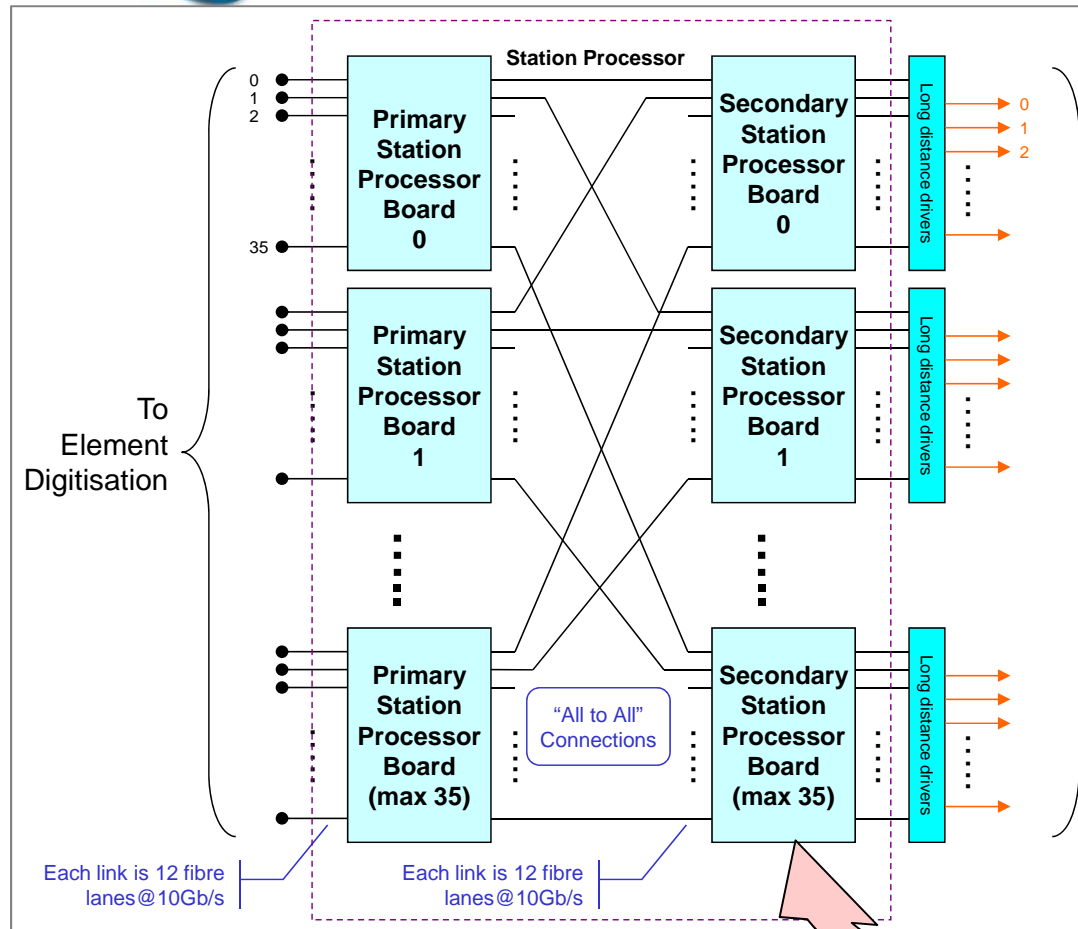


# AA-low signal path



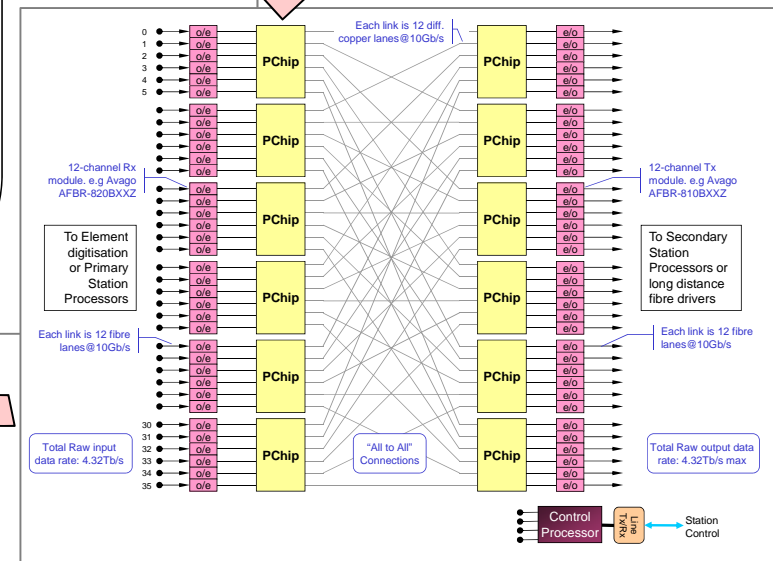
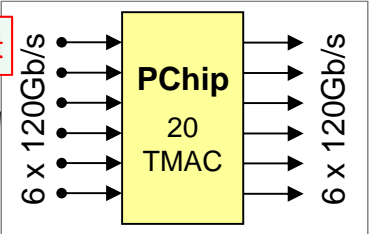
## Requirements:

- High bandwidth in
- High bandwidth out
- Largely cross connected
- Scaleable at various levels
- Programmable beamforming



Optical links  
To Correlator

25 watt



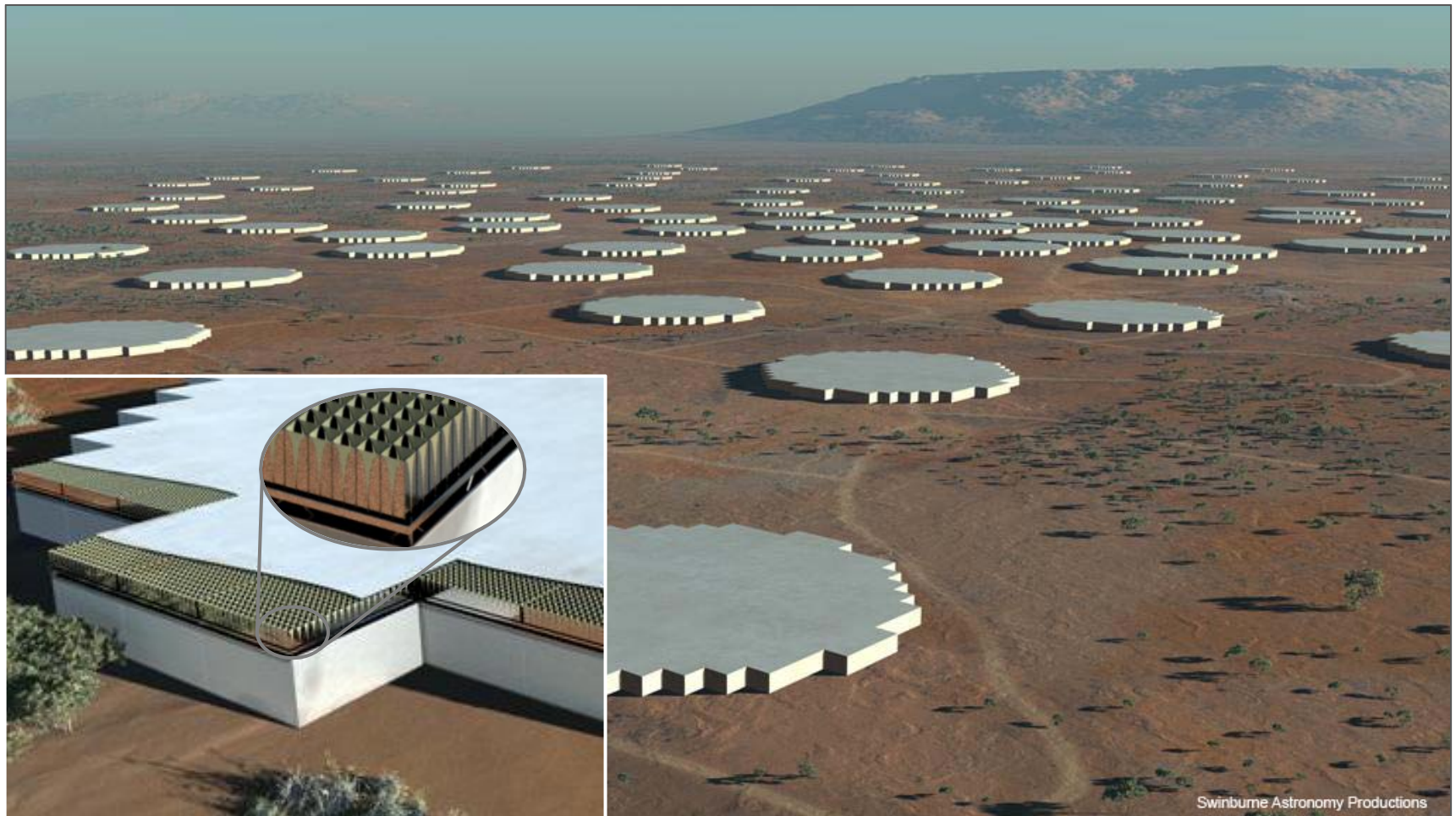
# SKA<sub>2</sub> AA Station processor

# SKA<sub>2</sub> AA-low Power

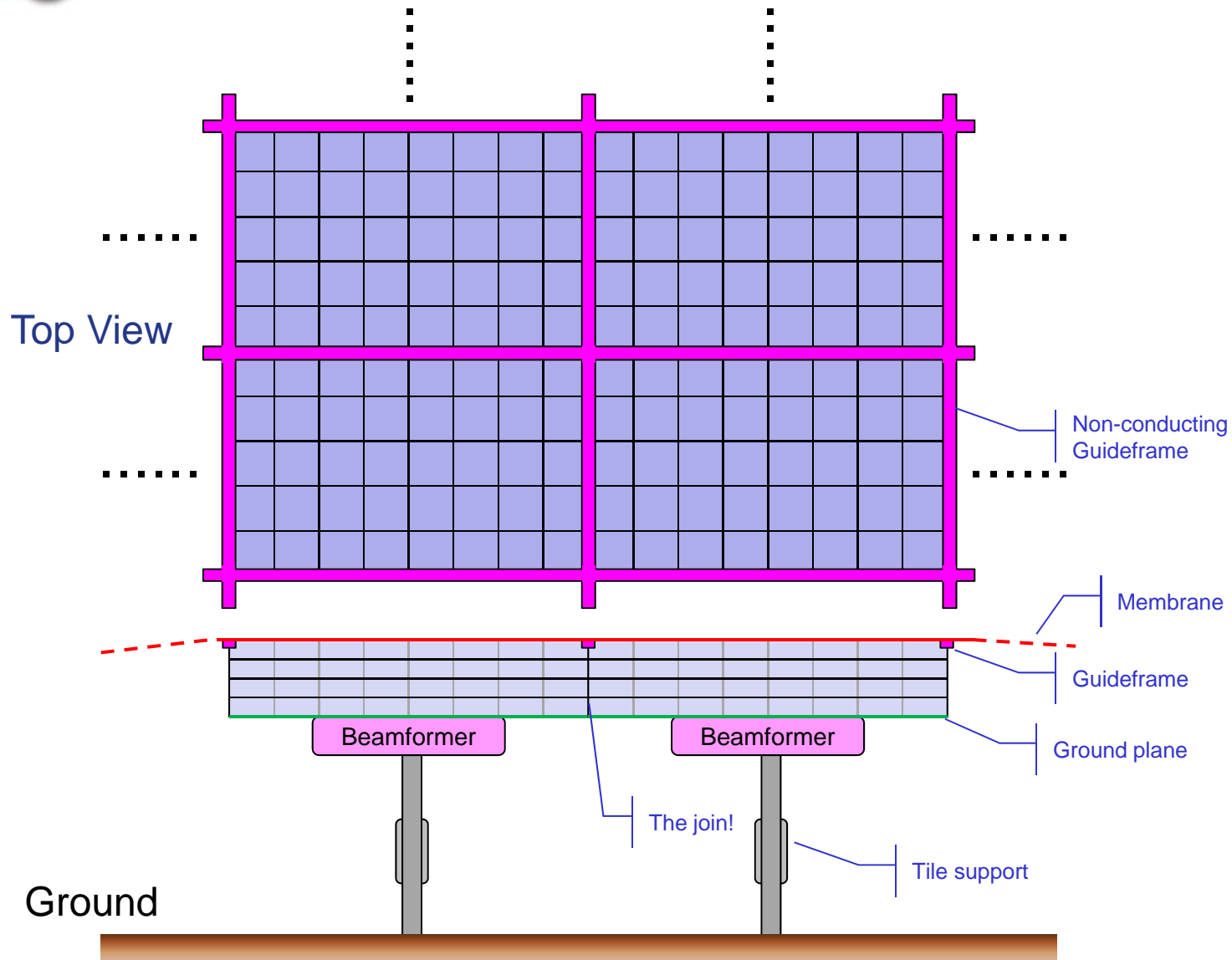
	Subsystem	SKA <sub>2</sub> mW	Remarks
	<i>Antenna element:</i>		
1	LNA	50	Projection from SKADS work
2	Antenna gain block	40	
	<i>Digitisation and processor:</i>		
3	Analogue sig conditioning	40	Estimate
4	ADC	75	1.0 GS/s each channel
5	Clock distribution	10	estimate (less with more ADC per chip)
6	<i>Coms:</i> ADC to processor		Phase 2: integrated ADC and processor
7	Digitiser Processor	300	SKA2: 40 W for 128 receiver inputs
8	Digitiser Control ccts etc.	140	SKA2: 25 W for 128 receiver inputs
9	<i>Copper comms:</i> Processor to optical driver	10	1.2 W for 128 receiver inputs
10	<i>Optical Coms:</i> Tile to Station proc.	60	SKA1: 4.4 W. SKA2: 2.5 W for 40 receiver inputs
	<i>Station Processor:</i>		
11	Primary Station processor	75	SKA2: 600 W. for 7776 receiver inputs
12	<i>Copper comms:</i> Processor to optical driver	10	1.2 W for 128 receiver inputs
13	<i>Optical Coms:</i> Primary to Secondary Station proc.	20	SKA2: 2.5 W for 40 receiver inputs
14	Secondary Station processor	75	SKA2: 600 W. for 7776 receiver inputs
15	<i>Copper comms:</i> Processor to optical driver	10	16 Tb/s station output with 153,000 receivers @ 10mW/Gb/s
	<i>Long Distance comms:</i>		
16	Wide area comms		Accounted for separately
	<b>Electrical power used</b>	<b>915</b>	
	Electrical power supplied @ 85% efficiency	1,076	
	Power incl cooling at 25% cooling power	1,345	
	<b>Total station power</b>	<b>31 kW</b>	



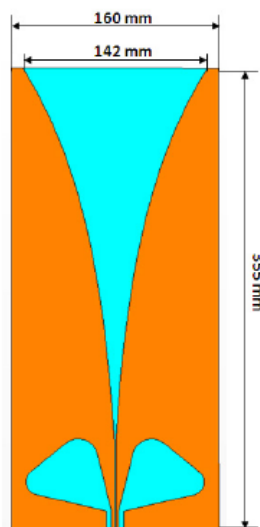
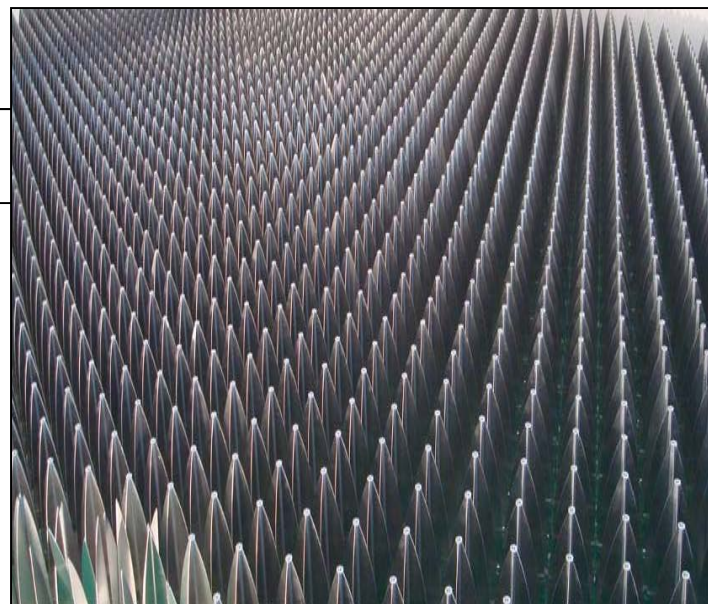
## AA-mid Array – SKA<sub>2</sub>



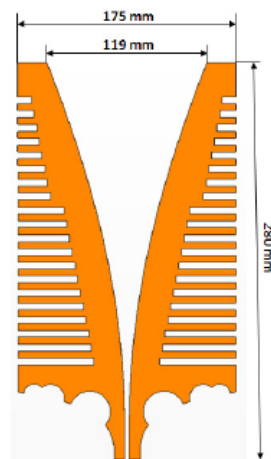
# Possible AA-mid construction



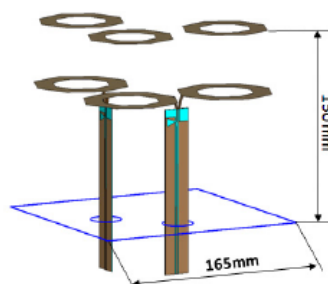
Vivaldi



(a)



(b)



(c)



(d)



(e)



(f)

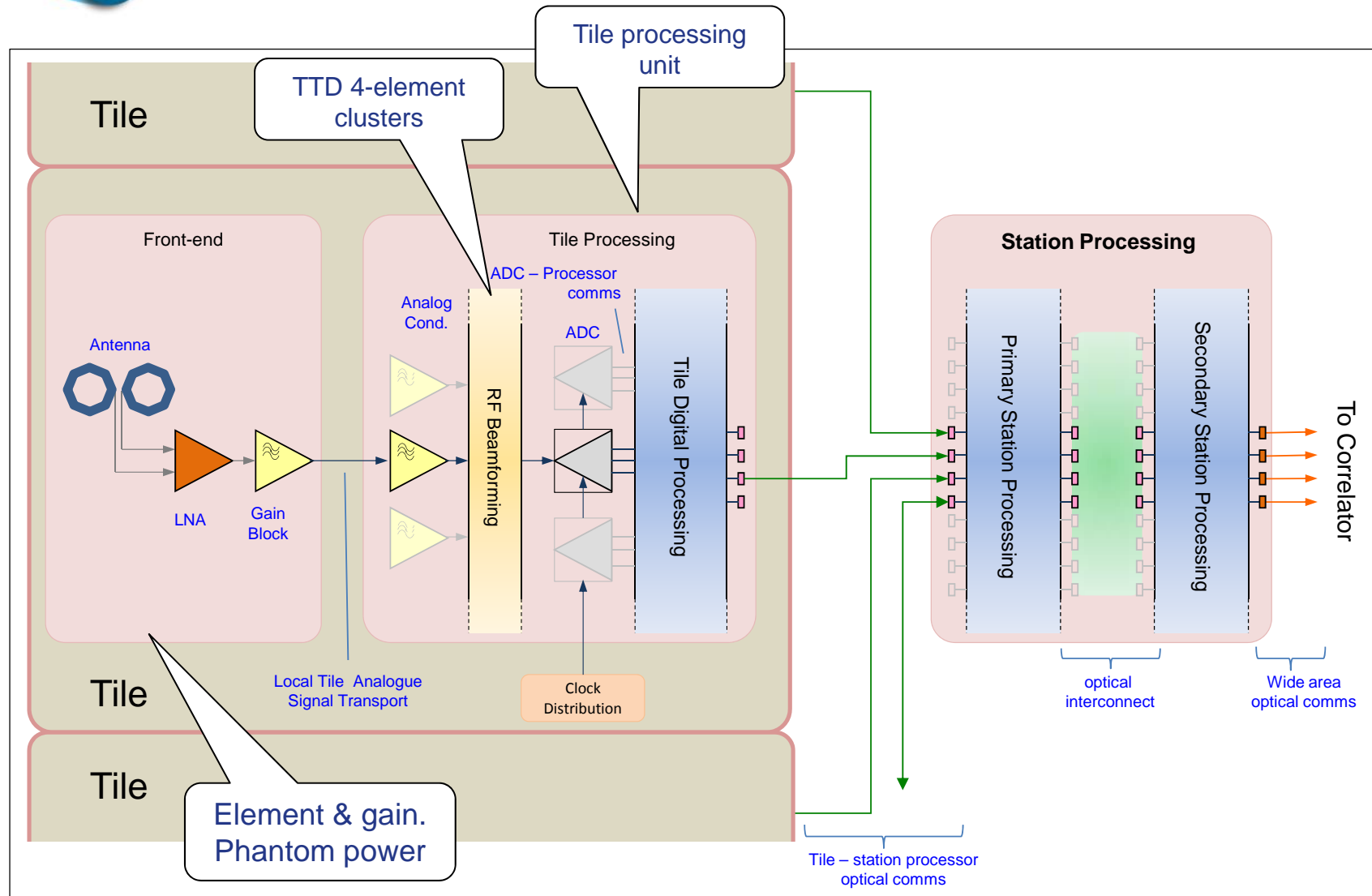
**FLOTT: (a)(d)**

**BECA: (b)(e)**

**ORA: (c)(f)**



# AA-mid proposed signal path



Parameter	Value	Comments
Type of array	Single element	Dense array using Vivaldi or ORA.
Number of elements	110,000	
Pitch of elements	15 cm	$\lambda/2$ at 1000MHz
No. of polarisations	2	Each element has two receiver chains
Diameter of station	56m	
Cluster size	4 elements	Uses true time delay beamforming
Tile size	16 x 16 elements	Built out of 4 x 4 clusters
No. of Tiles	430	Each tile is ~2.4m square
Number of stations SKA <sub>2</sub>	250	Anticipated number of Phase 2 SKA Stations
Element communication	Copper	Includes Phantom power
Layout	Dense rectangular	Regularly spaced
Frequency range	400-1450 MHz	
Digitisation rate	3GSamples/s	There is no frequency conversion,
Digitisation depth	6/8-bit	Required for RFI environment at these frequencies
Beamforming technology	Digital	Using cluster outputs
Max inst. bandwidth	1000 MHz	Covers operating band of array
Max output data rate	16Tb/s	Organised as 4+4bit complex data

# AA-mid Power

	Subsystem	SKA <sub>2</sub>	Remarks
	<i>Front-end (Quads of 4 elements):</i>	mW	
1	LNA total	120	4xLNAs at 30mW each
2	Antenna gain block	120	4 units at 30mW each
	<i>Tile beamformer:</i>		
3	Analogue sig conditioning	160	4 channels at 40mW each
4	Analogue beamforming	100	Combiner for 4 elements for digitisation
5	ADC	50	2.5 GS/s, 10Gb/s each channel
6	Clock distribution	10	estimate (less with more ADC per chip)
7	<i>Coms:</i> ADC to processor		Integrated ADC and processor
8	Tile Processor	200	25 W for 128 digital channels
9	Tile Control ccts etc.	100	13 W for 128 digital channels
10	<i>Copper comms:</i> Processor to optical driver	10	1.2 W for 128 digital channels
11	<i>Optical Coms:</i> Tile to Station proc.	20	2.5 W for 128 digital channels
	<i>Station Processor:</i>		
12	Primary Station processor	130	600 W for 4608 digital channels
13	<i>Copper</i> Processor to optical driver <i>comms:</i>	10	1.2 W for 128 digital channels
14	<i>Optical</i> Primary to Secondary Station proc. <i>Coms:</i>	20	2.5 W for 128 digital channels
15	Secondary Station processor	130	600 W for 4608 digital channels
16	<i>Copper comms:</i> Processor to optical driver	10	16 Tb/s station output with 153,000 receivers @ 10mW/Gb/s
	<i>Long Distance comms:</i>		
17	Wide area comms		Accounted for separately
	<b>Electrical power used</b>	<b>1,190</b>	Per digital channel
	Electrical power supplied @ 85% efficiency	1,400	
	Power incl cooling at 25% cooling power	1,750	
	<b>Total station power</b>	<b>96 kW</b>	



# 2018+ Technology Shopping list

AA Power challenges  
can be met with realistic  
developments\*

$T_{\text{sys}}$ for AA-mid	<40K
Analogue system power	100mW per Rx
>3GS/s ADC power	<100mW
DSP processor chip performance	>20TMACs
DSP Power for 20TMAC	~25W
DSP chip comms, I/O count	>128 x 11Gb/s
DSP-digitiser <b>integration</b>	Possible
50m optical links, pluggable	>120Gb/s
50m 120Gb/s link power	2.5W
Flash storage module capacity	20TB
Many-core streaming processor	>50TFlop
50TFlop processor power	<300W
Super computer performance	>10PFlop
Super computer power	<1MW/PFlop

\* e.g. International Technology Roadmap  
for semiconductors, ITRS