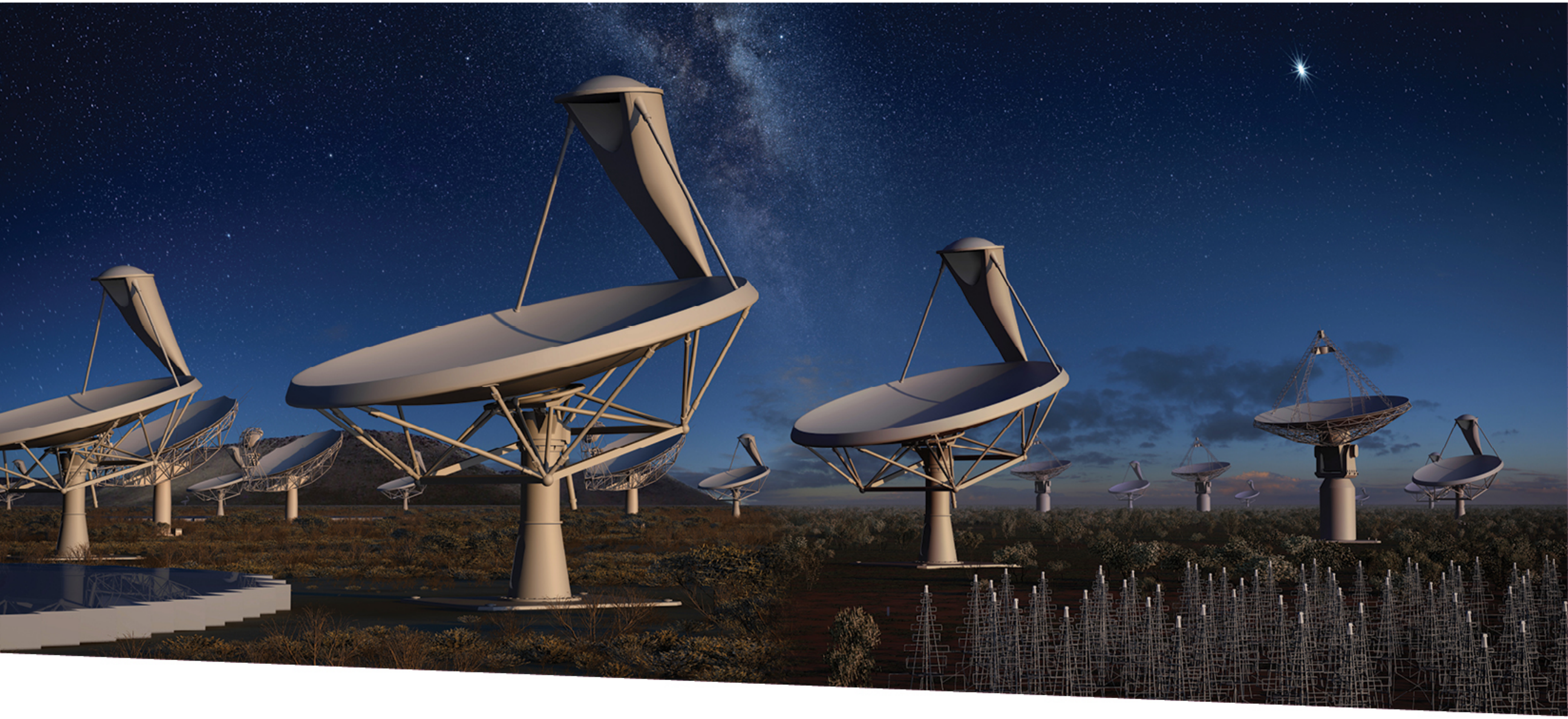
SKA1-LOW CONFIGURATION CONSULTATION WS



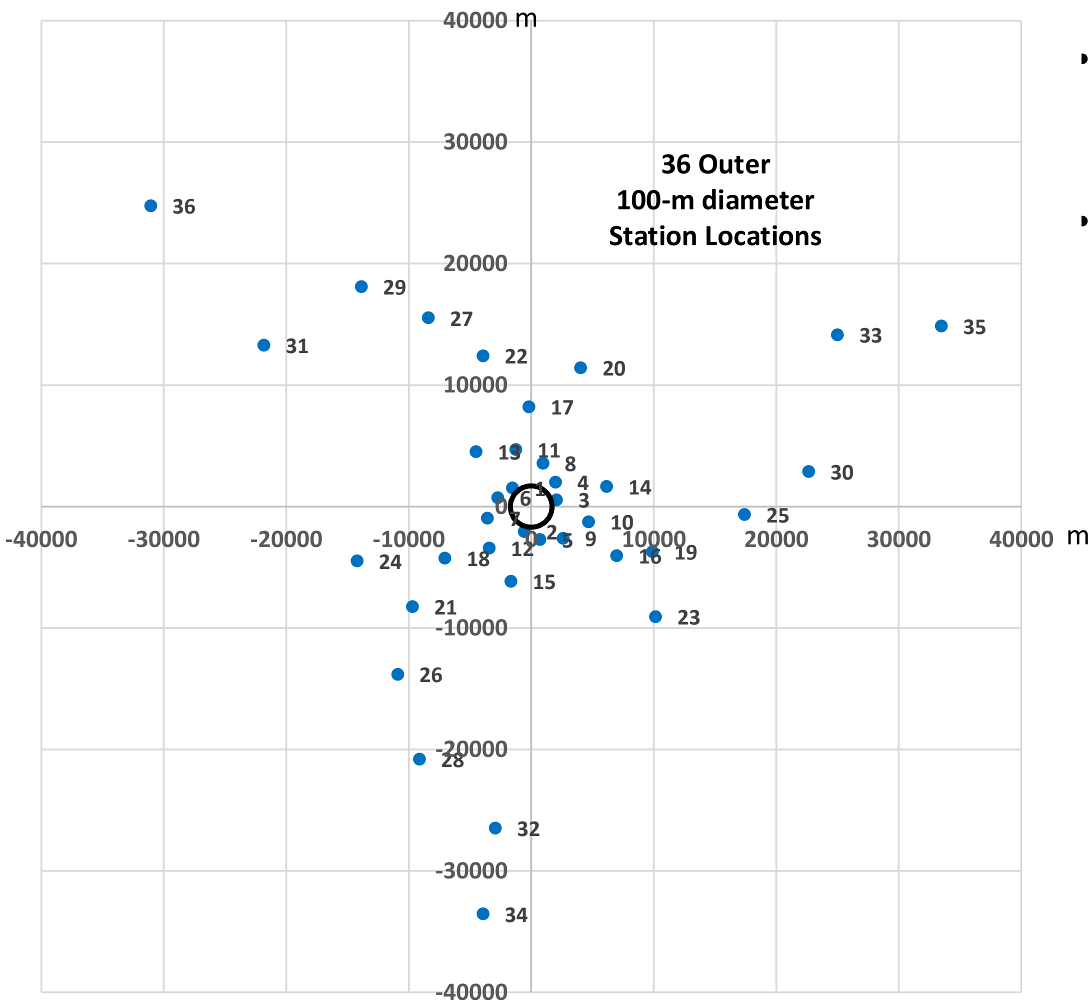
SQUARE KILOMETRE ARRAY

Exploring the Universe with the world's largest radio telescope

P. Dewdney

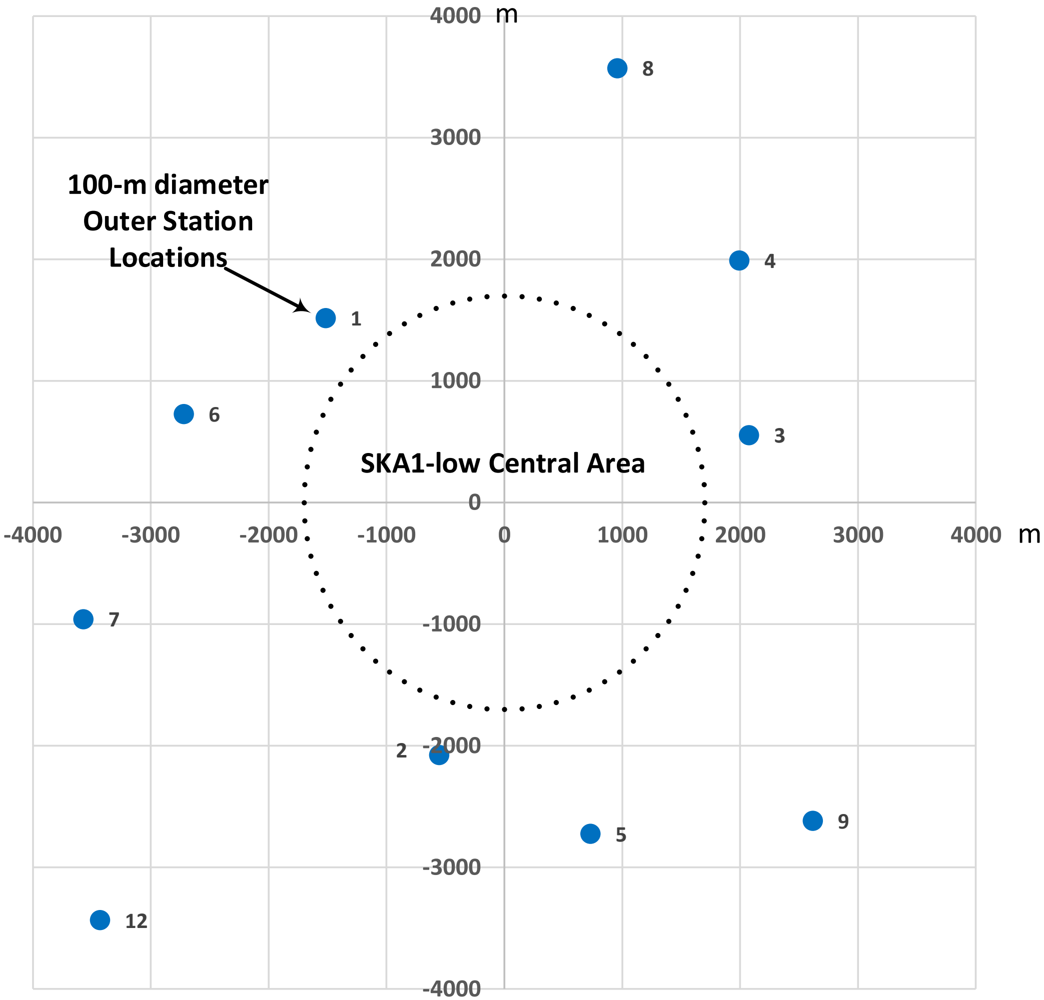
2016-02-25

Current Status of Definition – Outer Stations



- The dots indicate the positions of stations, not the size or internal configuration.
- Changes will require a well justified ECP.

Current Status of Definition – Inner Part



- The dots indicate the positions of stations, not the size or internal configuration.
- The central area was left undefined at that time.
- Current goal is to define this.

Ionospheric Calibration & FG Subtraction (EoR/CD)

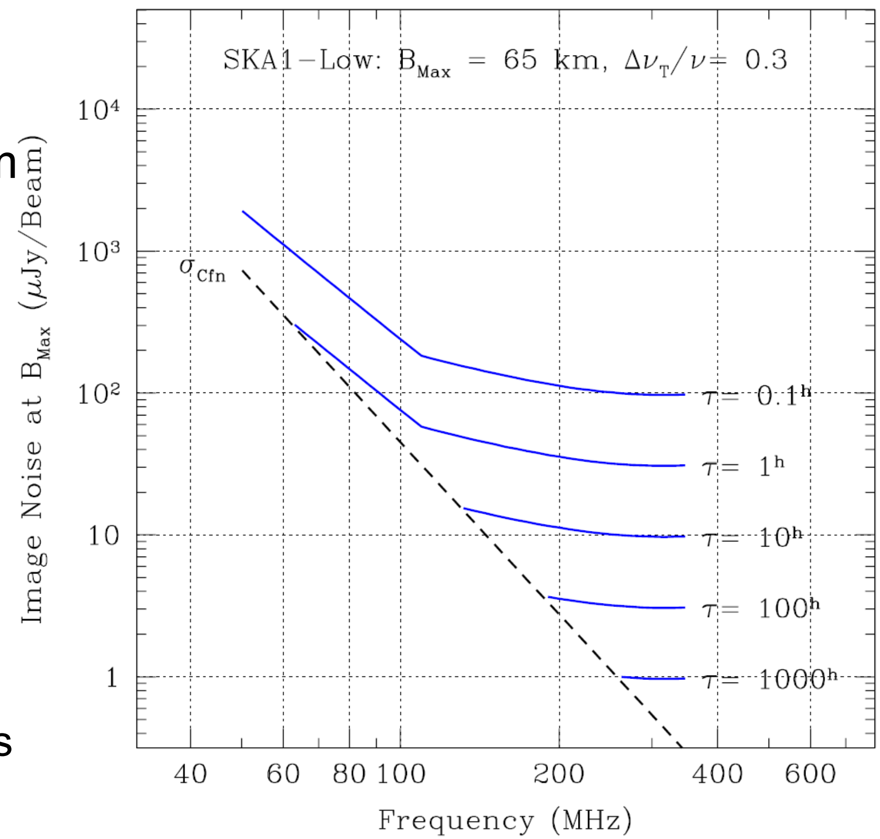
- These were discussed in the meeting on Dec 1, 2015.
- Present configuration of outer stations:
  - Sufficient number of ionospheric ‘pierce points’ with the currently adopted configuration of outer antennas.
  - Sufficient signal-to-noise ratio depending on station size adopted.
- For foreground source subtraction,
  - Important to provide sufficient u-v coverage to enable reliable subtraction.

Purpose of Workshop

- Consider options for the antenna configuration for stations:
  - individual outer stations in SKA1-low
  - the detailed antenna configuration within a radius of 1700 m
- Expected Outcome:
  - a sufficiently detailed description of the configurations of the antennas in outer stations and stations within the core to complete the design of the balance of the SKA1-low system.
- Context:
  - three main science areas:
    - EoR/CD (power spectrum and deep line imaging),
    - Pulsar search and timing,
    - Standard imaging.
- Put together a series of questions to guide the process.
  - Hopefully the presenters will provide their input to the answers.

Imaging Capability

- This general capability is both the most difficult ('pushes' system design) and the most scientifically important.
- For EoR/CD, discovering the power spectrum will be very significant if not previously discovered by other telescopes or experiments,
  - but the investment in SKA1-low is really justified by 3-D spectral-line imaging.
- For Standard imaging (continuum and spectral line), imaging capability is self-evident.
- SKA1-low continuum surveys are not seriously impacted by confusion noise down to a frequency of ~110 MHz, except for very long integration times
  - See confusion plot
  - Note, of course it will never be confusion limited for narrow spectral line observations.



- Based on parameters shown at the top (Braun).

Important Factors in the Station Design

- Sufficient diameter in wavelengths to reduce far-out sidelobes to an acceptable level.
- The acceptable level of near-in sidelobes.
- Sufficient collecting area for on-sky calibration (self-calibration of offset calibration).
- Smooth spatial response over the field-of-view in a single beam or in a mosaic of beams.
- Sufficient field-of-view for EoR/CD imaging.
- Polarisation response that can be accurately modelled and/or measured.
- The signal-to-noise ratio for sources that aid in the characterisation of the ionospheric phase-screen.
- The fixed total number of antenna elements has an impact on station diameter: if there are too many antenna elements in each station, the number of stations will be too small.
- The sky noise spectrum is increasing rapidly at low frequencies.
- The sparse-dense transition (see next slide)

The Sparse-Dense Transition

- Average spacing of antenna elements is $\lambda/2$ at the formal transition.
- The sparse-dense transition should be at the lowest frequency possible (to extend the range where collecting area goes as λ^2).
- On the other hand, the sparse-dense transition should be as high as possible, since the entire part of the frequency range that is in the sparse regime suffers reduced brightness sensitivity.
- Antennas that are too wide will have to be spaced far apart within a station, which in turn will generate ‘grating lobes’ (or similar) at high frequencies.
- The low-frequency response will be compromised if the low-frequency ‘dipoles’ on the antenna elements are too short (in wavelengths).

‘Entities’ that can be beamformed & correlated

- Broadly based on ‘SKA1-low Configuration, v4A’ document:

- Station
  - One array of antenna elements arranged within a fixed diameter;
- Superstation + station
  - Similar to item 1, except that the entire superstation (aggregation of stations) can be beamformed in addition to each station;
- Superstation + station + substation
  - Similar to item 2, except that a station can also be sub-divided in smaller arrays called sub-stations.

‘Entities’ that can be beamformed and correlated

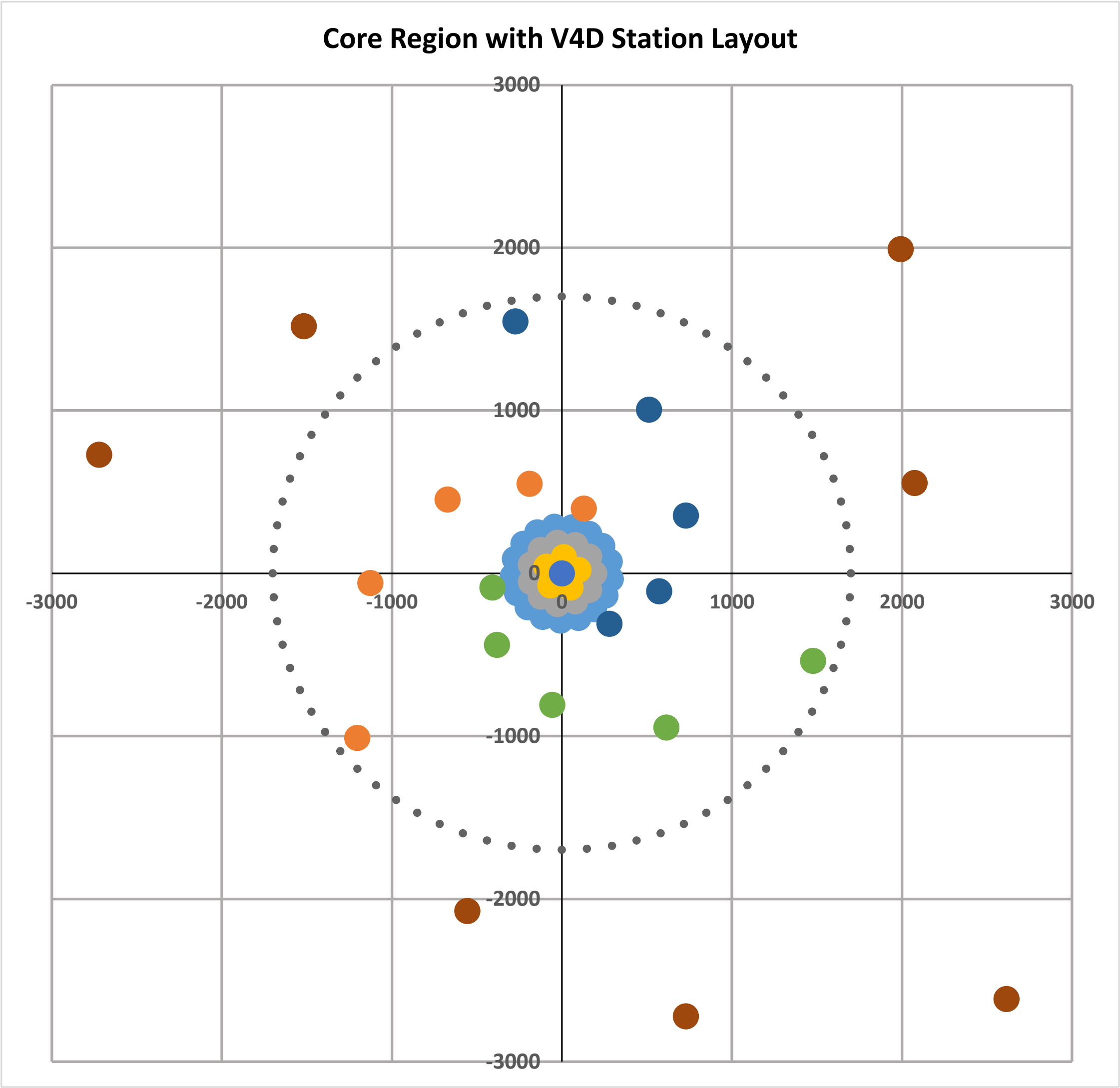
Table 1: Properties of SKA1-low Station Configurations			
	BD - RBS	V4A	V4D
Total number of antennas	131072	162432	131072
Antennas per station	256	288	256
Number of stations	1	6	6
Number of sub-stations	N/A	6	N/A
Number of outer superstation/stations	48 stn’s	36 s-stn’s	36 s-stn’s
Average ant. Element spacing (m)	1.5	1.5	1.5
Antennas per superstation	N/A	1728	1536
Antennas per sub-station	N/A	48	N/A
Total antennas in outer stations	12288	62208	55296
Antennas in core (radius < 1700 m)	118784	100224	75776
Fraction in core (%)	91%	62%	58%
Diameter of Superstation 'Sea' (m)	N/A	70	66
Diameter of Station 'Sea' (m)	27	29	27
Diameter of Superstation (flower) (m)	N/A	86	81
Superstations in core	464	58	49
Total Superstations	512	94	85
Correlatable entities			
Superstation	N/A	94	85
Station	512	564	512
Substation	N/A	3384	N/A
Max baselines	130816	5724036	130816

- The discussion at the meeting will need to centre on something specific.
- Columns
  - Left: Baseline Design – after re-baselining
  - Middle: V4A configuration as per Braun et al document.
  - V4D: default configuration
- Total number of antennas is not likely to increase.

Notes on V4D adapted from V4A:

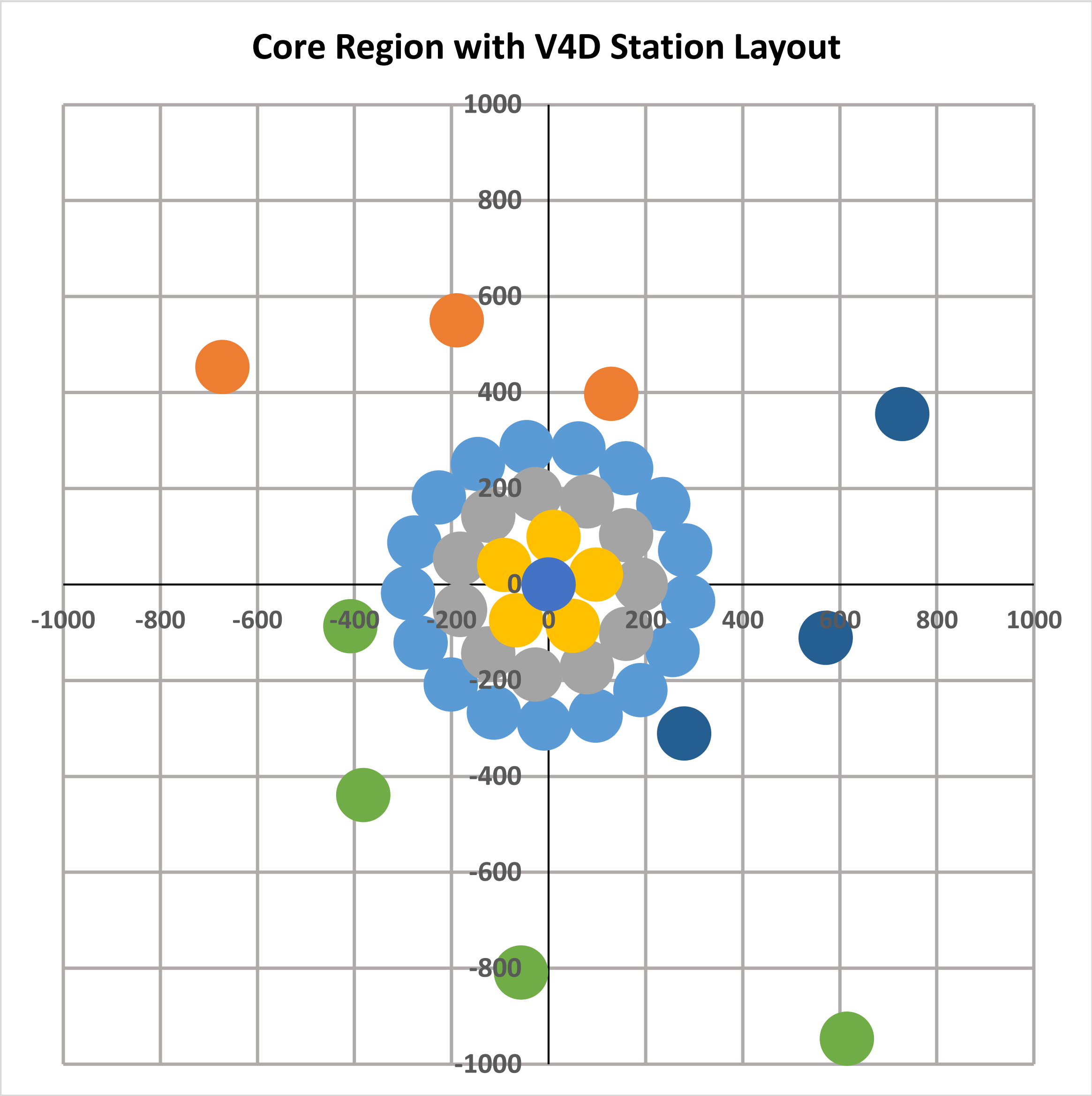
- Total number of antenna elements (same as for RBS baseline design): 131072.
- Number of antenna elements per station also same as BD-RBS: 256.
- Retain the number of outer station positions: 36 (established earlier).
- No physical substations.
- Retain average spacing between antenna elements at 1.5 m.
  - However, this may have to be increased if the antenna design must be increased in size in order to improve its band-shape.
  - The impact would be to decrease the sparse-dense transition frequency.
- Features of the Central region (< 1700 m radius) retained (4 rings plus 3 spirals):
  - Number of superstations in core adjusted from 58 to 49.
  - Number in each ring (1, 5, 11, 17) – reduced by 3.
  - Radii: 0, 100, 190, 290 m.
  - Four superstations in each spiral arm – reduced by total of 6.
  - Odd number of superstations in each ring.

V4D – Inner Region of Configuration



- Default configuration (V4D)
- Dots are superstations.
- The dotted circle is the previously undefined region (1700 m radius).

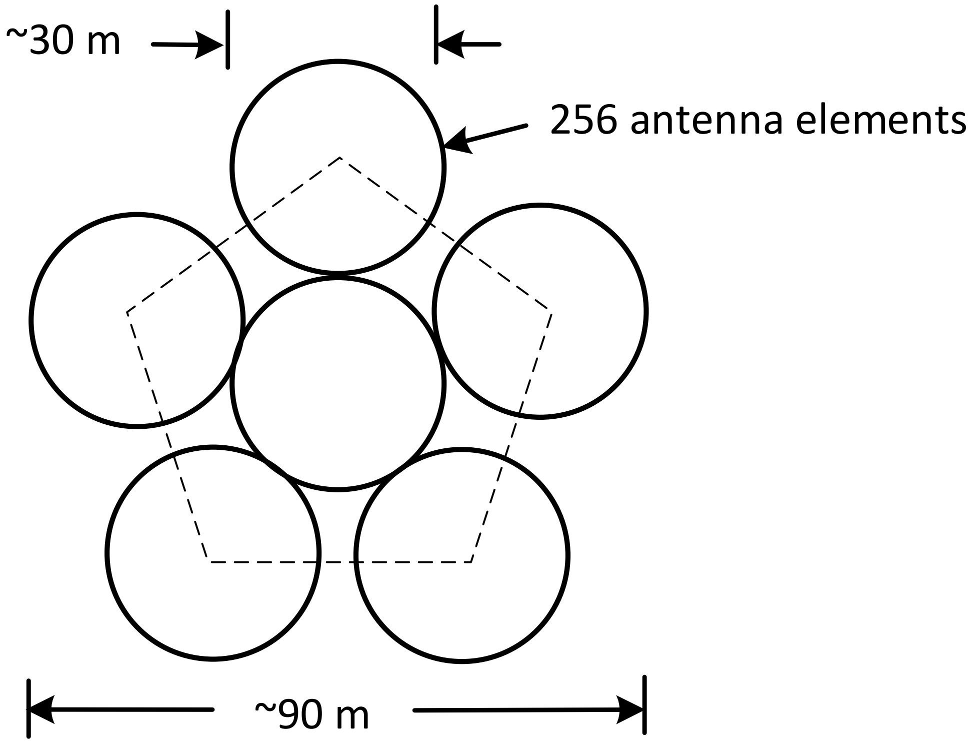
V4D – Core Region



- An exploded view of the default array configuration showing the core.

Super-station Structure (V4D)

V4D Station Configuration



- In principle, substations can be created virtually within the station footprint.
- May be possible for a limited subset of the total number of stations.
- Enables very short spacings.

End

Key Questions

1. What is the ideal station diameter if only one can be chosen (option 1)?
   - Single baseline signal-to-noise on calibration.
   - In the EoR white paper by Mellema et al. (2013), the recommended station diameter was based on minimum FoV size, which primarily emphasises power spectrum observations.
2. What is the scientific argument for multiple station sizes?
   - One station size cannot work for all of the main science uses (see above). Why not?
3. What is the minimum acceptable ratio of collecting area in the core to outer stations?
   - Station size and core size are linked for a fixed number of available antennas. Increased outer-station size implies less area in the core.
4. Must all stations antenna configurations for a given observation be identical?
   - For imaging this would normally be considered a given.
   - Are there cases in which outer stations with smaller/larger FoV would be used to calibrate a core containing stations of a different diameter?

Key Questions (cont'd)

5. If there are three station diameters allowed (sub-stations, stations and super-stations), which of the above scientific areas will benefit and how? What are the ideal superstation, station and substation sizes?
   - Superstations will reduce the instantaneous field-of-view but provide greater control of station side-lobes.
   - If substations are allowed, it is unlikely to be possible to correlate them all (because of the large number).
6. What are the technical impediments to multiple station diameters?
   - Multiple station diameters in the spiral arms may require a more complex beam-former.
7. What are the technical impediments to building and using sub-stations or superstations?
   - If substations are allowed, it is unlikely to be possible to correlate them all (because of the large number).
8. What is the argument for/against 'physical tapering'?
9. What is the ideal density of antennas in a station and the associated sparse-dense transition frequency?
10. What would be the cost/benefit of a 'sea of antennas' approach for a superstation, in which the stations and substations are formed virtually through the beamforming process?
    - Flexibility. Potentially permit multiple station sizes.
    - Probably result in a loss of collecting area, since some antennas would not be used or weighted down.