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The high angular resolution component of the SKA

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Manchester

1 = ICRAR; 2 = AARNet; 3 = AUT

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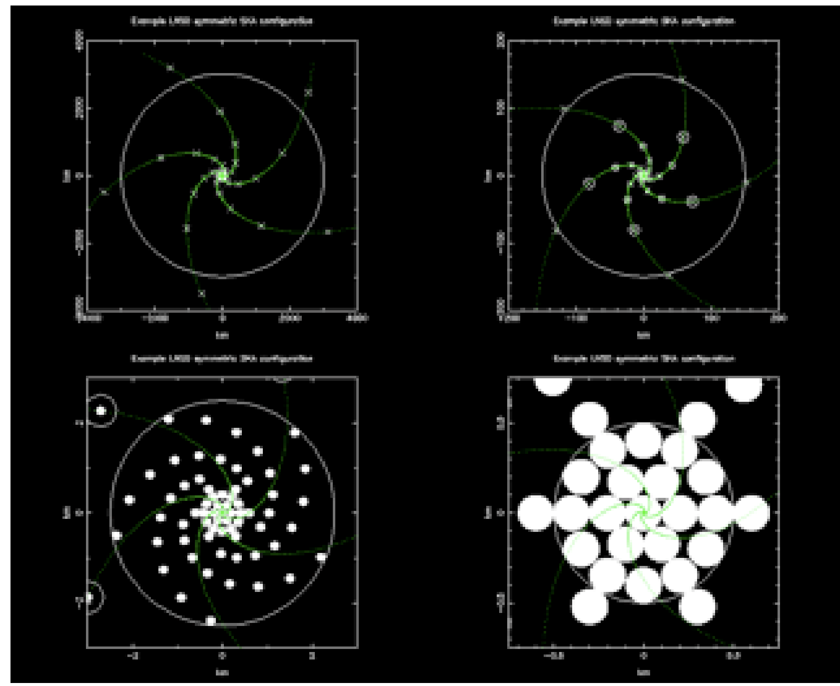
Outline

- SKA long baseline specifications;
- High angular resolution science for the SKA;
- Technical requirements and functional requirements for SKA remote stations;
- Cost minimisation for the SKA long baselines;
- A deployment strategy for SKA remote stations and long haul data transport;

Basic SKA long baseline specifications

SKA memo #100 (Schilizzi et al. 2007), specifies that the Phase 2 SKA has 25% of the collecting area placed at distances greater than 180 km from the core site, up to at least 3000 km from the core.



These remote stations could be in the form of 25 stations each containing 24 x 15 m antennas.

Angular resolution $\theta \propto \lambda/d$ (where d is the distance between stations):

- At 10 GHz, $\theta \sim$ 2 mas for a 3000 km baseline;
- At 1 GHz, $\theta \sim$ 20 mas for a 3000 km baseline;

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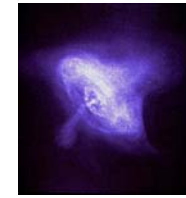
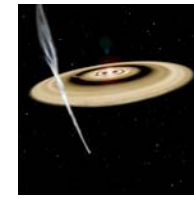
High angular resolution science for the SKA

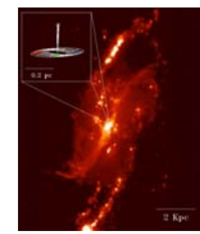
- Strong field tests of gravity using pulsars and black holes:
  - Headline science: pulsar distances via direct parallax measurements
  - Other science: Scattering studies of ISM



- The cradle of life:
  - Headline science: Imaging protoplanetary disks **(Graeves talk)**
  - Other science: Localisation of candidate SETI signals



- Galaxy formation, cosmology and dark energy:
  - Headline science: N/A
  - Other science: Water masers; AGN and star formation in galaxies **(Smail talk)**; HI absorption against AGN; OH masers; OH absorption and changes in the fundamental constants



- Cosmic magnetism:
  - Headline science: N/A
  - Other science: N/A
- Probing the dark ages and the epoch of reionisation:
  - Headline science: N/A
  - Other science: The first galaxies and black holes
- Exploration of the unknown:
  - Localisation, identification and understanding of new types of compact radio emission – transients
  - AGN evolution and jet physics, binary black holes **(Fender, SPF panel)**; gravitational lensing; scattering in the ISM/IGM; precision astrometry; X-ray binaries; star formation and stellar evolution
  - Geodesy, planetary and solar system science (incl. spacecraft tracking)

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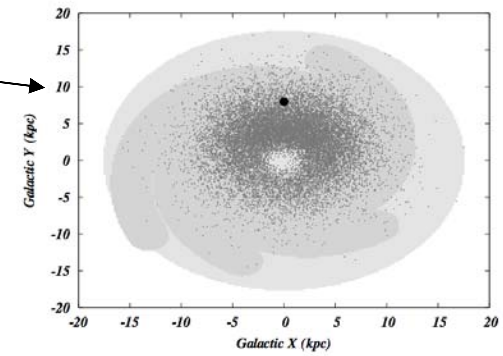
Pulsar distances via direct parallax measurements

Simulation of an SKA pulsar survey in our galaxy using method of Lorimer et al. (2006), resulting in 15,258 pulsars detectable by the SKA.



High angular resolution observations of all pulsar-BH candidates to determine precise distances (Kramer et al. 2004).

Used to correct for Galactic and kinematic contributions to the rate of change of the binary period (Deller et al. 2009). Also, measure ionised gas distribution in galaxy.

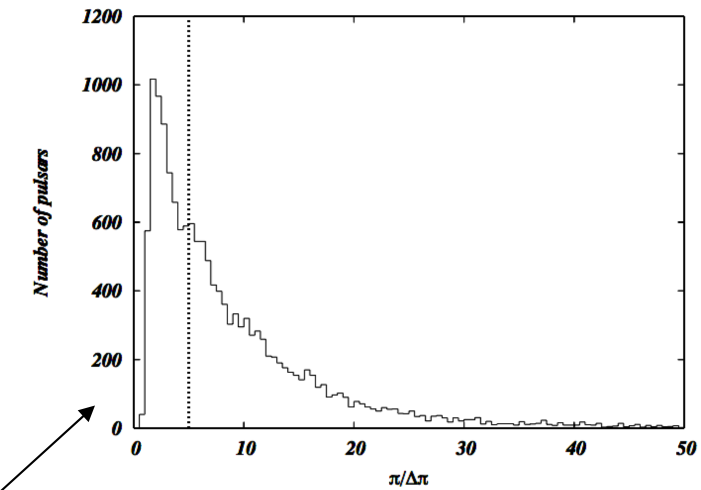
How to measure the distances to these pulsars?

Using timing parallax method:

– Parallax with 20% accuracy for 300 millisecond pulsars to 20 kpc.

Using interferometric imaging parallax method:

– Parallax with < 20% accuracy for ~9000 pulsars (all comers) to 13 kpc.



Smits, Tingay, Kramer & Stappers (in preparation)

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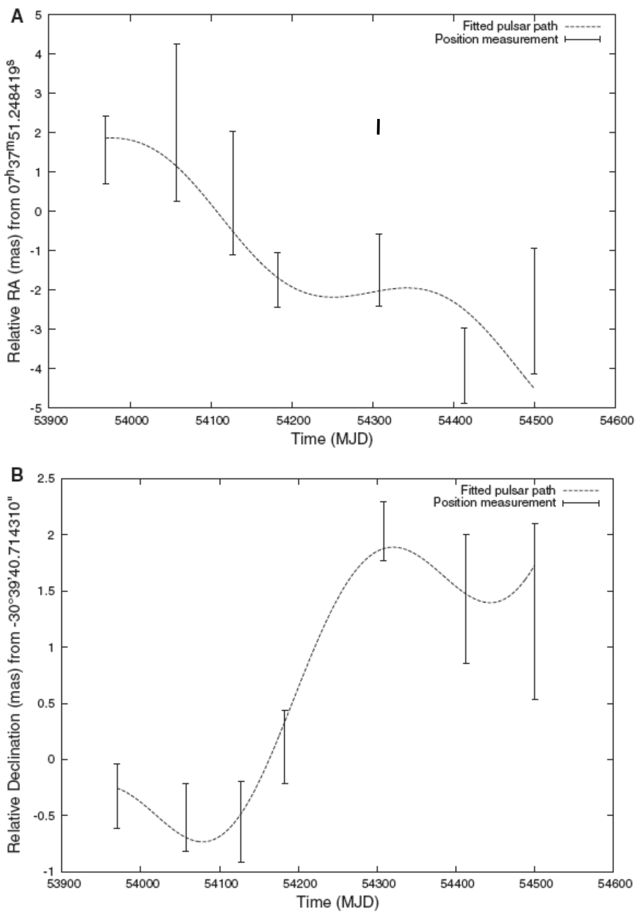
Example with current technology (Australian Long Baseline Array) - the double pulsar

"Implications of a VLBI Distance to the Double Pulsar J0737-3039A/B"

Deller, Bailes & Tingay, 2009, Science, 323, 1327



Distance derived from geometric parallax from Interferometry:	1150 pc (930 - 1310 pc) ~20% error
Distance derived from dispersion Measure:	470 pc ?? error
Distance derived from pulsar timing parallax:	333 pc (200 - 1000 pc) ~100% error

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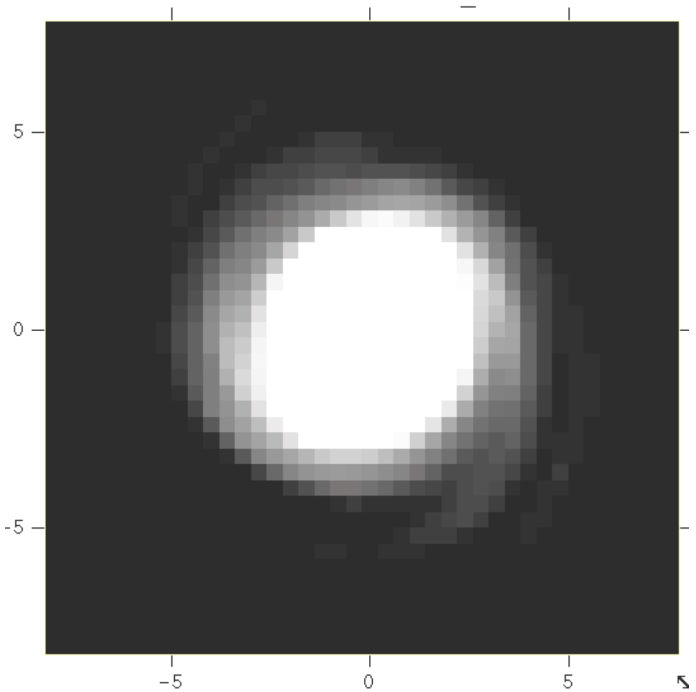
Imaging protoplanetary disks

High resolution observations for imaging and monitoring of proto-planetary disks and terrestrial planet formation.

Originally proposed as a high frequency experiment but recently re-examined in terms of <10 GHz frequencies (Melvin Hoare, 2009, PrepSKA Work Package 2 Annual Meeting).

Also, talk at this meeting by Dr Graeves.



Initial simulation
At 5 GHz, with
structure on ~40 mas
scales (Hoare 2009)

Direct detection of the formation of Earth-like planets.

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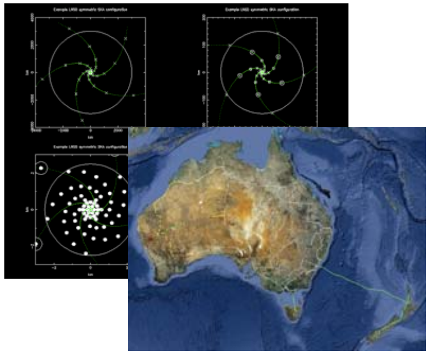
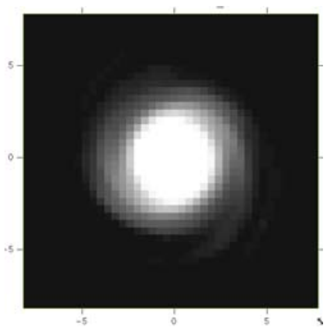




Adopt UVGEN simulation engine in the MIRIAD package (Willis 2000). Modified by Stuart Weston from AUT for large N arrays.

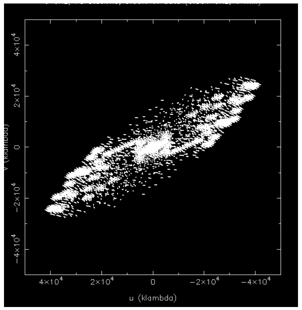
Written a script-based wrapper to UVGEN that runs parallel simulation over a Beowulf cluster:

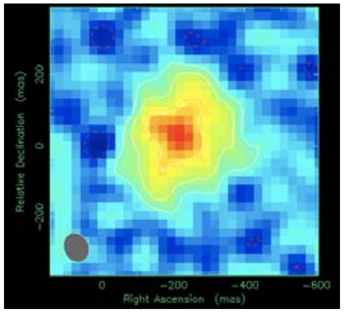
- 20 node (160 core: dual-processor, quad-core);
- 2 TB disk per node;
- 8 GB RAM per node;
- Embarrassingly parallel problem (multiplex simulation in time and frequency).

+ UVGEN

Test simulation of SKA, focused on long baseline performance:

- 78 stations (central distribution as tied arrays of antennas);
- 20 minute duration;
- 10 second visibility sampling;
- Stokes I;
- 5 GHz centre frequency;
- 1 GHz bandwidth;
- 1 MHz channel bandwidth;
- 3000 individual simulations over 160 cores;
- ~5 TB of visibility data distributed over 20 machines!





Imaging of 0.03% (~2 GB) of simulated data

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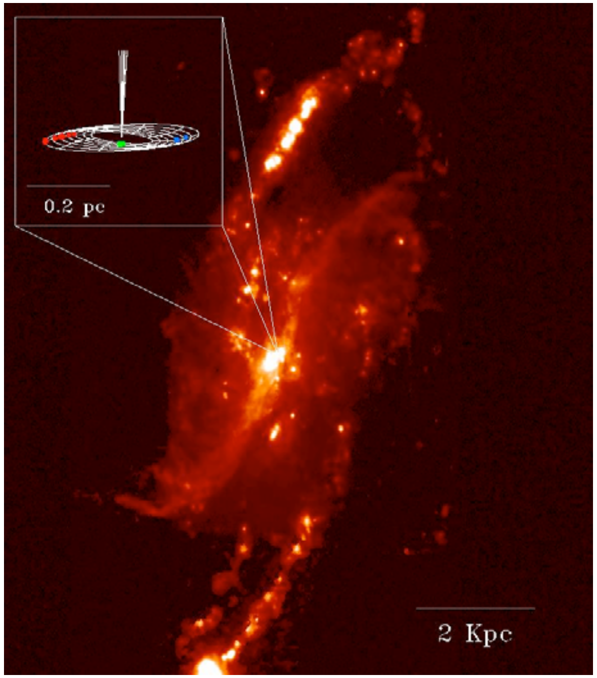
Water masers and cosmology

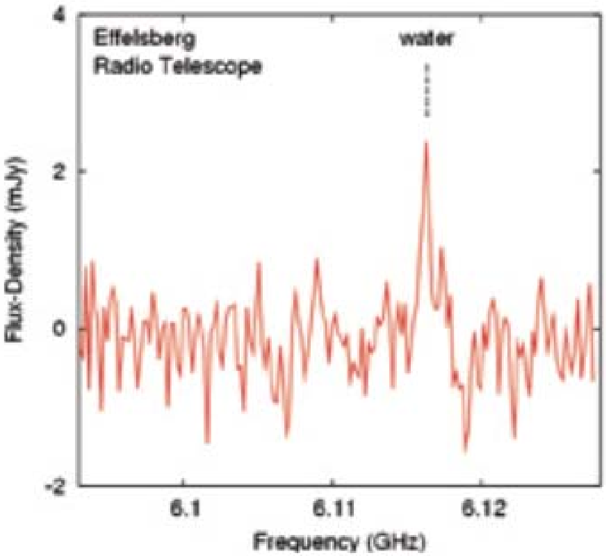
Miyoshi et al.



Measurement of accurate distances to galaxies by observing water masers in gas disks rotating around black holes e.g. NGC 4258.

Originally proposed as a high frequency experiment. Not possible with current SKA Phase 2 plan. Thus, not part of “headline science”.

However, recent discovery of redshifted maser at z = 2.64 (gravitationally lensed) mean that this experiment may be possible in the 1 - 10 GHz frequency range. And high redshift water masers may be abundant.



Impellizzeri et al. 2009, Nature

Technical requirements and functional requirements for SKA remote stations

– Many target objects are simple in structure (point source or collection of point source):
  - Exceptions are proto-planetary disks, AGN etc;
  - Extreme imaging dynamic range not required;
  - IMAGING DYNAMIC RANGE ~ 10,000.

– Very wide fields of view are not required for:
  - “headline science” or;
  - most other science (AGN, X-ray binaries etc);
  - FIELD OF VIEW OF ~30’.

– Strong need for very accurate phase reference calibration:
  - CONTINUOUS OBSERVATIONS OF MULTIPLE PHASE REFERENCE CALIBRATORS BY CLUSTER-CLUSTER OR MULTI-BEAMING (~4 SIMULTANEOUS CALIBRATION TARGETS).

– Most important science does not need low or high frequencies:
  - Most low or high frequency science can largely be recast for this frequency range;
  - FREQUENCY RANGE OF 1 - 10 GHz => SPWBF FOR REMOTE STATIONS.

– High angular resolution required, 2 - 50 mas:
  - BASELINE LENGTHS OF 200 - 3000 km.

– Full sensitivity required for some but not all science:
  - 25% OF COLLECTING AREA IN THIS BASELINE RANGE;
  - FRACTIONAL BANDWIDTH OF 25% => ~1 Tbps PER STATION MAXIMUM DATA RATE (4 SIMULTANEOUS BEAMS).

Cost minimisation for the SKA long baselines

- Simple examinations of long baseline costs focus on digging own fibres or leasing managed bandwidth or dark fibre at commercial rates.

- A more creative approach to funding the long haul data transport is required to minimise costs.

- One strategy is to place remote SKA stations close to existing fibre routes and collaborate with next generation research networks for high bandwidth SKA data transport:

  - Implication is that long baseline costs will be highly dependent on the site and cost estimates therefore need to take these dependencies into account.

- National Broadband Network (NBN) and possible resultant access to long-haul dark fibre for next generation research applications provides an opportunity that should be explored.

- e-VLBI and ASKAP relationships in Australia between researchers and network providers (AARNet/NBN) are blazing the trail to develop this opportunity.

A deployment strategy for SKA remote stations and long haul data transport

Over a 5 - 10 year period, at least two aspects of long-haul data links will evolve strongly:

- Continued rapid deployment of network infrastructure ;
- Higher datarates per wavelength will be possible, from 10 Gbps to 40 Gbps, 100 Gbps and maybe beyond.

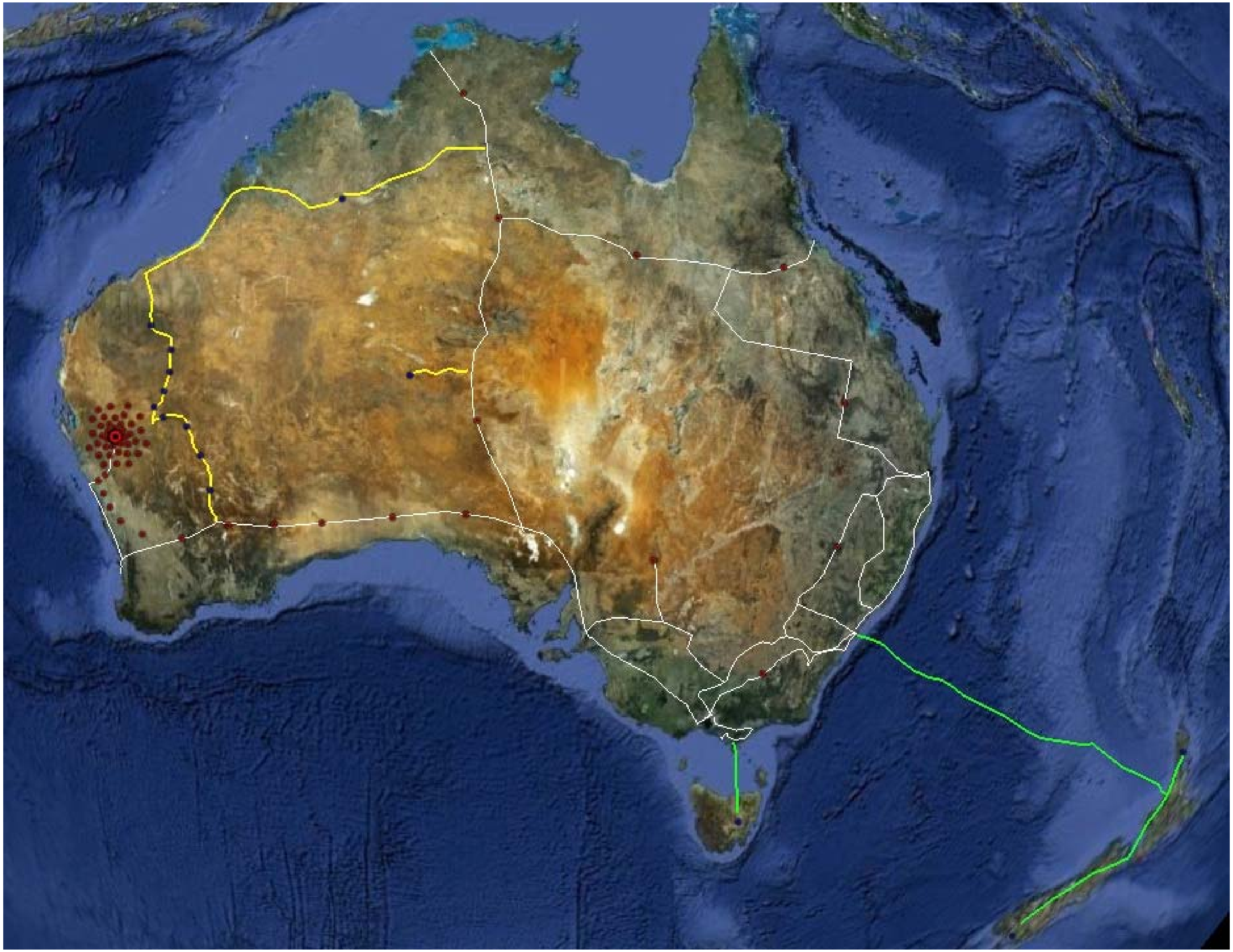
Strategy:

- Initially deploy remote stations to existing fibre routes in a scientifically meaningful manner, at relatively low data rates (<100 Gbps);
- Gradually deploy further remote stations to fibre routes as they become available and at higher datarates as technology permits.

Outcome:

- Provide a very cost effective and flexible solution for the SKA long baselines. Flexibility to deploy and expand sensibly over time;
- Over time other upgrade paths for the remote stations may be possible (frequency coverage etc);

Illustrating these points…………



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Summary

- High angular resolution science features as part of two areas of “headline science” for SKA Phase 2, requiring baselines of 1000 - 3000 km. Plus a raft of other areas of science, known and unknown;
- Technical requirements for remote stations are simpler than for the stations/antennas within 180 km radius;
- In order to be affordable, the long baseline SKA must maximally utilise existing infrastructure, in particular network infrastructure;
- Remote station deployment strategies are possible that allow maximum flexibility now and far into the future;
- Data transport requirements over next decade are within the projected technology and national infrastructure deployment envelopes.