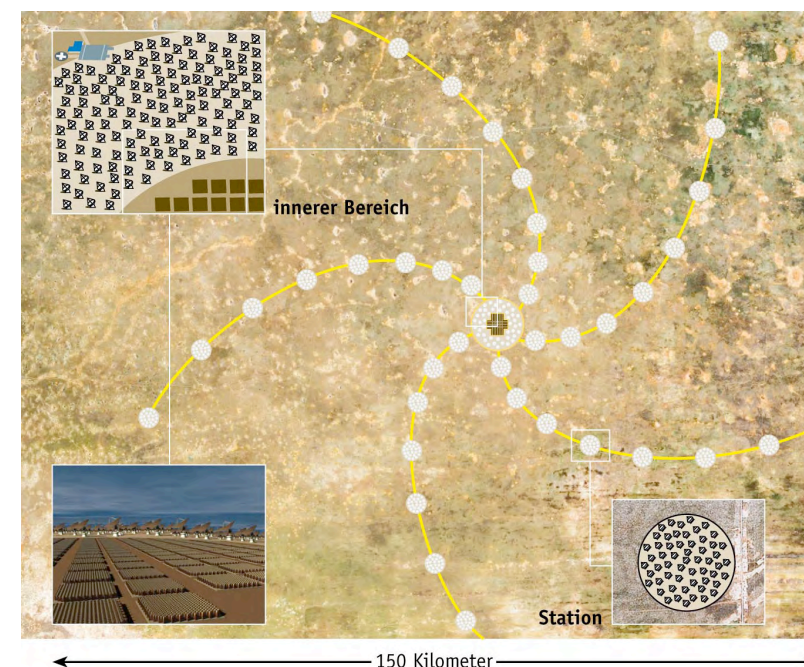
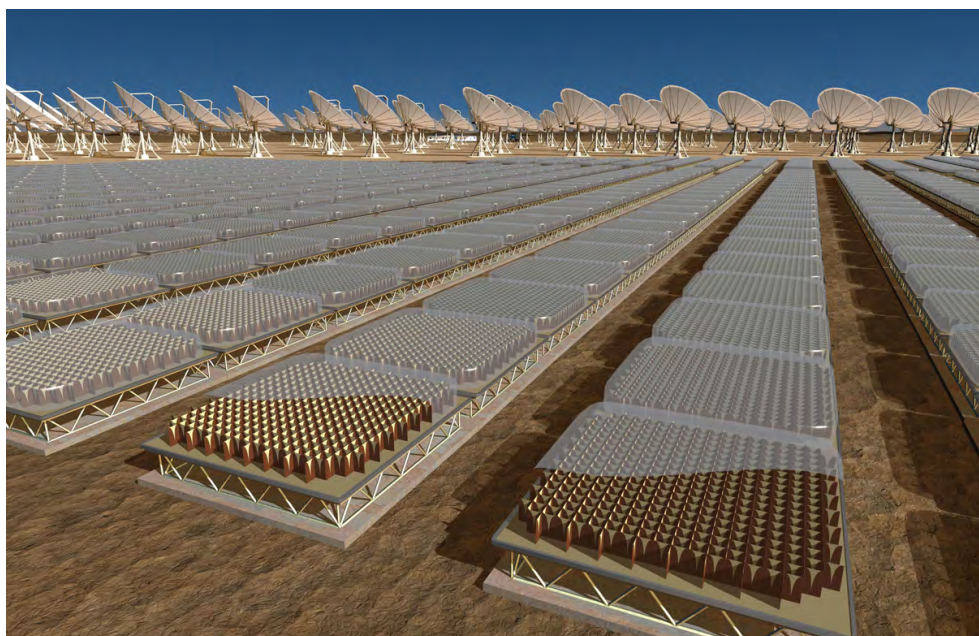




Square Kilometre Array & SKADS



Steve Torchinsky
SKADS Project Scientist
Observatoire de Paris



SKA & SKADS



- Some history
- Science goals
- SKA reference design and demonstrators
- SKADS
 - Science interactions
 - Benchmark
 - EMBRACE demonstrator



Radio Schmidt



- 1990-91: Dewdney et al
- Analogous to the optical Schmidt telescope
- Large collecting area
- Large field of view
- Aperture synthesis

*Radio Interferometry: Theory, Techniques and Applications,
IAU Coll. 131, ASP Conference Series, Vol. 19, 1991,
T.J. Cornwell and R.A. Perley (eds.)*

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THE PROPOSED RADIO SCHMIDT TELESCOPE: THE TECHNICAL CHALLENGES

P.E. DEWDNEY and T.L. LANDECKER

Dominion Radio Astrophysical Observatory, Penticton, B.C., V2A 6K3

ABSTRACT The concept of the Radio Schmidt Telescope is designed to fill a scientific requirement for a radio telescope which is very sensitive to diffuse, extended emission, but has much higher resolution than single-antenna telescopes. This telescope undertakes to utilize a new region of “parameter space” in the aperture synthesis technique. The emphasis of this article is on a process leading to the best implementation of the concept at reasonable cost while satisfying all the scientific objectives.



HIA: Square Kilometre Array



- Wilkinson coins the phrase 1km² Array

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*Radio Interferometry: Theory, Techniques and Applications,
IAU Coll. 131, ASP Conference Series, Vol. 19, 1991,
T.J. Cornwell and R.A. Perley (eds.)*

THE HYDROGEN ARRAY

P.N. WILKINSON

University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank, Macclesfield, Cheshire, SK11 9DL, United Kingdom

ABSTRACT The time is ripe for planning an array with a collecting area of 1 km² (14 times larger than Arecibo and 75 times larger than the VLA). In view of its major astronomical target I have dubbed this concept 'The Hydrogen Array', although 1μJy continuum sources will also be reliably detected. I present some initial thoughts about the issues involved.



Misconception of stunted development in Radio Astronomy



- Arecibo is the largest collecting area since 1963
- In the same time frame, ~3 “generations” of optical telescopes: 2m, 4m, 8-10m
- Radio astronomy concentrated on other areas of development



image by SATorchinsky



Radio Astronomy Developments since the 1960's



- Synthesis telescope
 - Ryle Nobel prize
- VLBI
- Extremely high spectral resolution
 - Heterodyne receivers, correlators
- Low noise systems
 - amplifiers, mixers, receivers
- Signal processing
- Observing strategies
 - Position switching
 - Frequency switching
 - Pulsar timing



The Nobel Prize in Physics 1974

"for their pioneering research in radio astrophysics: Ryle for his observations and inventions, in particular of the aperture synthesis technique, and Hewish for his decisive role in the discovery of pulsars"



Sir Martin Ryle

🏆 1/2 of the prize

United Kingdom

University of Cambridge
Cambridge, United Kingdom

b. 1918
d. 1984



Antony Hewish

🏆 1/2 of the prize

United Kingdom

University of Cambridge
Cambridge, United Kingdom

b. 1924



SKA gets started



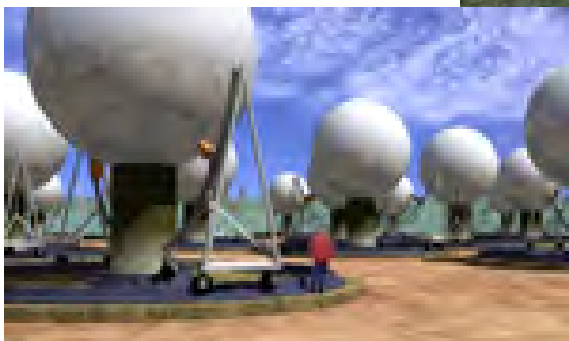
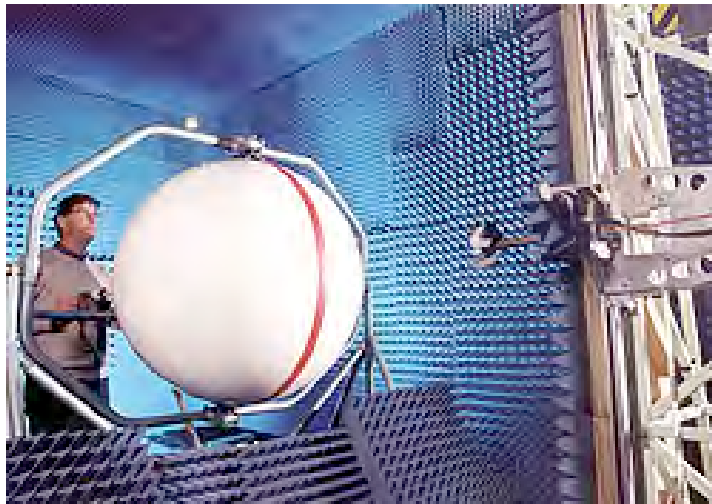
- 1991 initial concept
- 1994 International Working Group
- 2000 MoU
- Survey instrument
 - Large field of view (at least 1sq deg)
 - $O(10^2)$ more sensitive than current (1km^2)
- Main science motivation
 - HI survey of galaxies
 - HI mass function
 - (the idea of BAO was still to come)
 - Most distant galaxy in HI: $z \sim 0.18$ (still true)
 - Pulsar searching and timing



SKA Proposals: Australia



- Luneburg lenses





SKA Proposals: Australia (2)



- Cylinders
 - SKA Molongolo Prototype

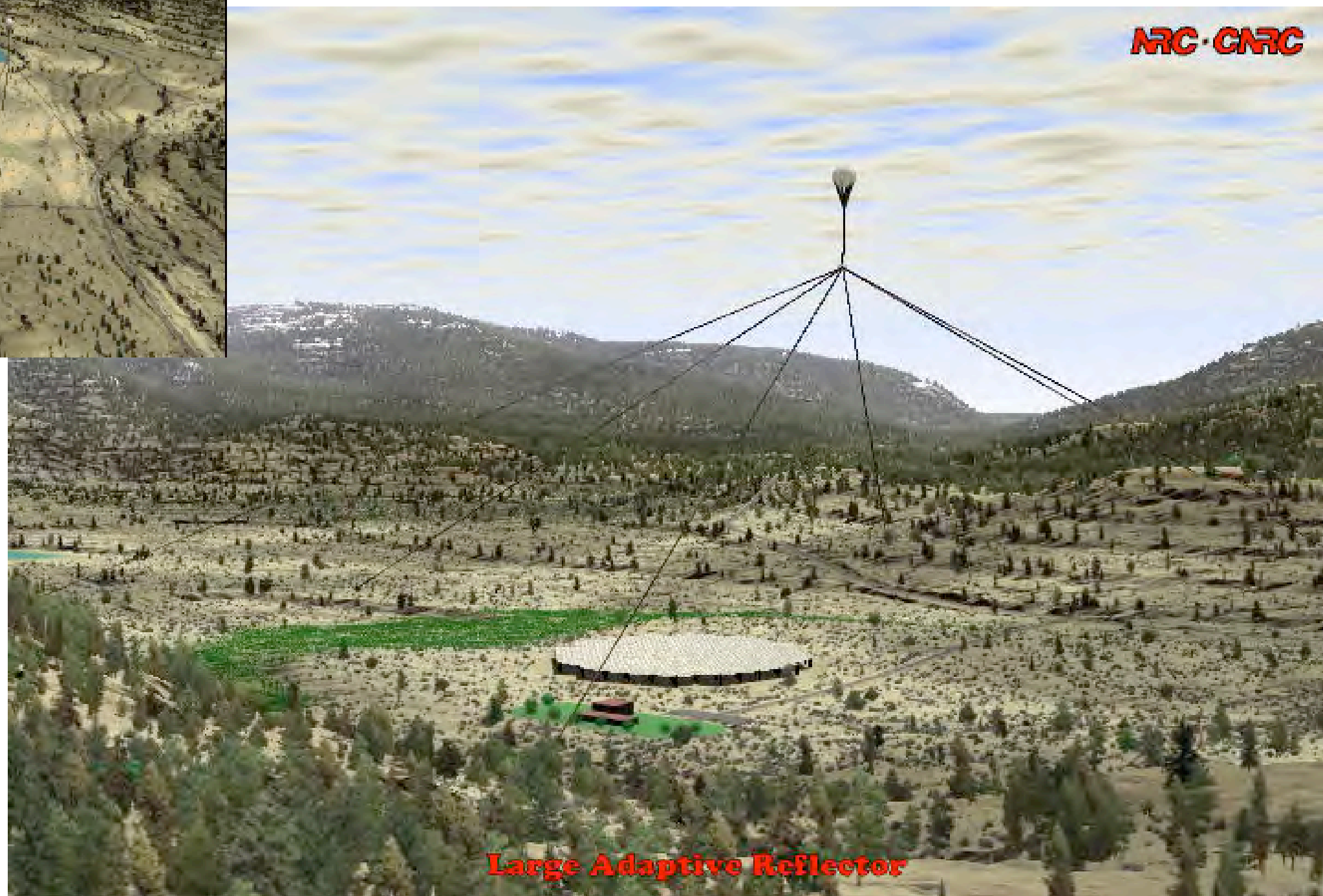
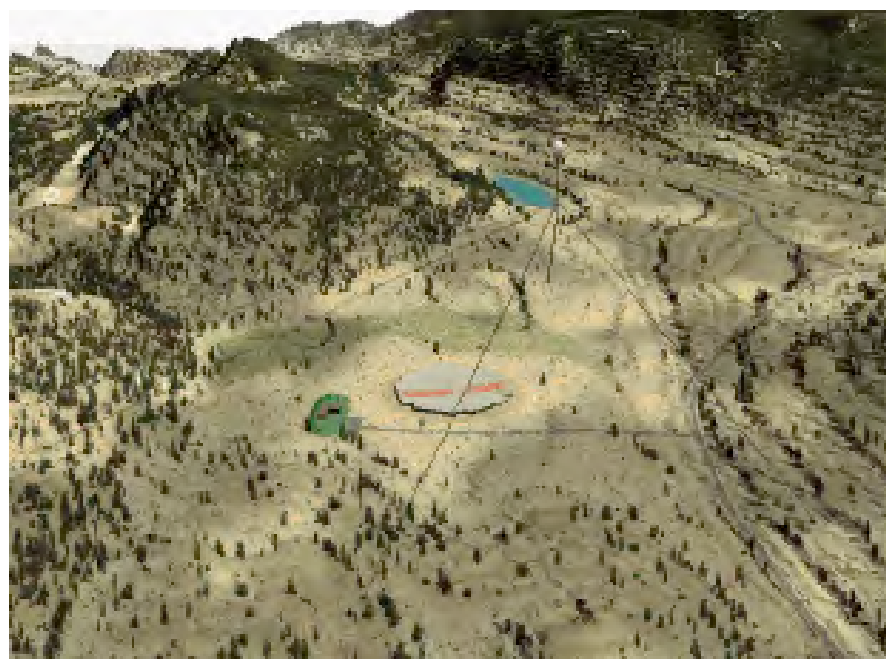




SKA Proposals: Canada



- Large Adaptive Reflector





SKA Proposals: USA



- Large N small D
- Allen Telescope Array
- Single pixel
- Wideband feed

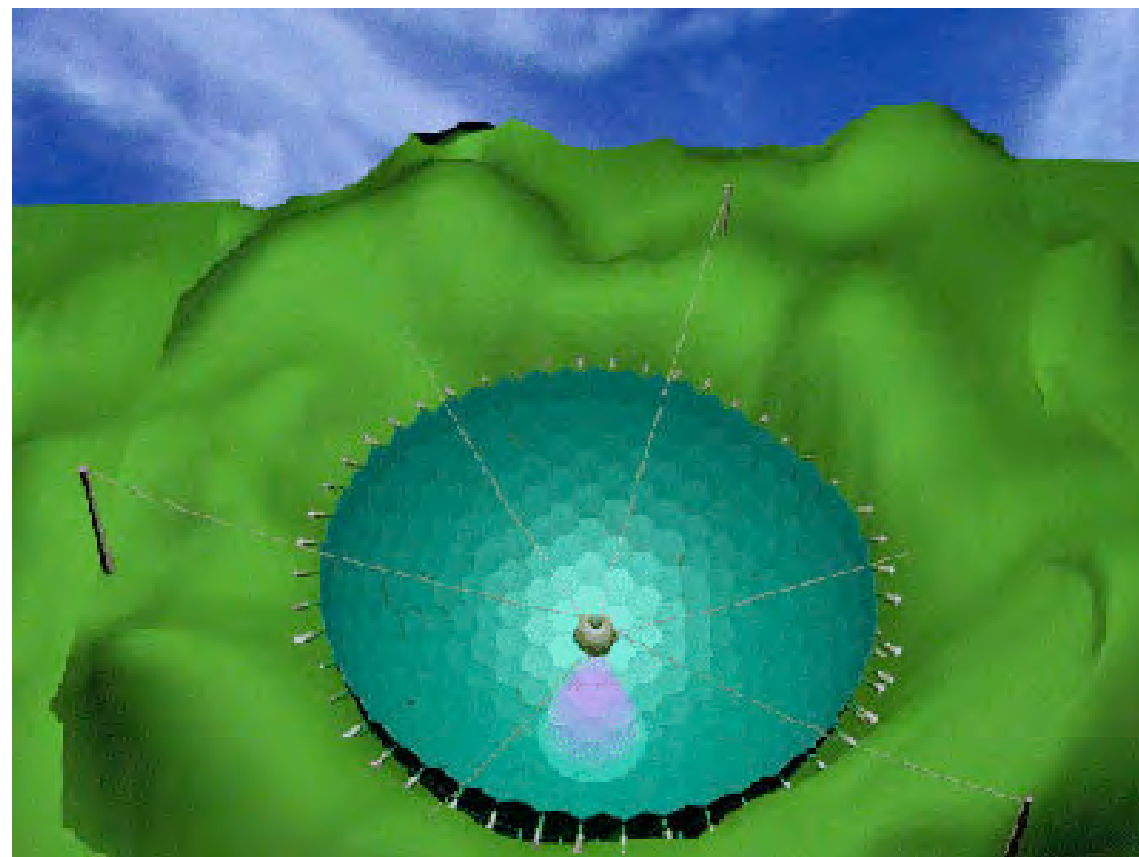




SKA Proposals: China



- FAST
- 500m Arecibo-like design with adaptive reflector





SKA Proposals: Europe (NL)



- Extremely large N , very small D
 - Dipoles for low frequency (LOFAR)
 - Densely packed aperture-plane phased-array (mid freq)
 - EMBRACE
 - Dishes (mid to high frequency)



2005: Key Science



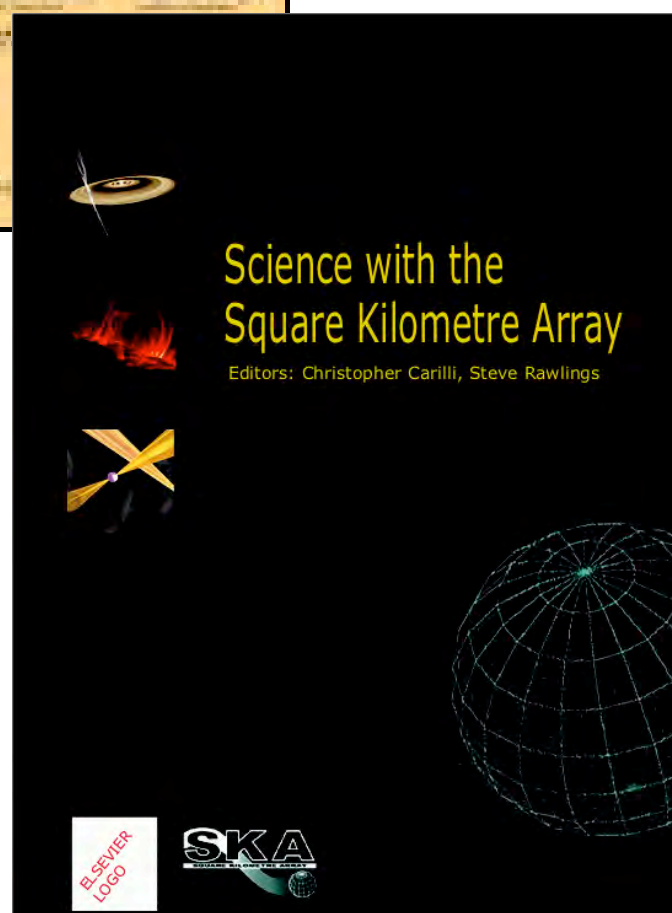
- Pune meeting: Key Science agreed
 - Large Scale Structure (HI galaxy survey)
 - Epoch of Reionisation
 - Cosmic Magnetism
 - Tests of General Relativity in extreme fields (Pulsars)
 - Cradle of Life (protoplanetary disks, planets, organic molecules)



SKA Science Book



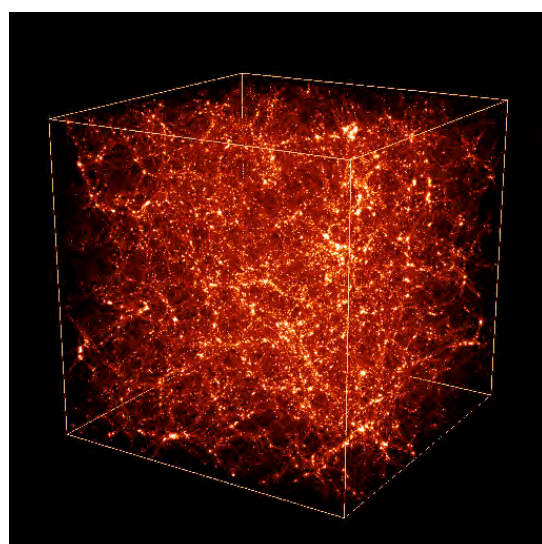
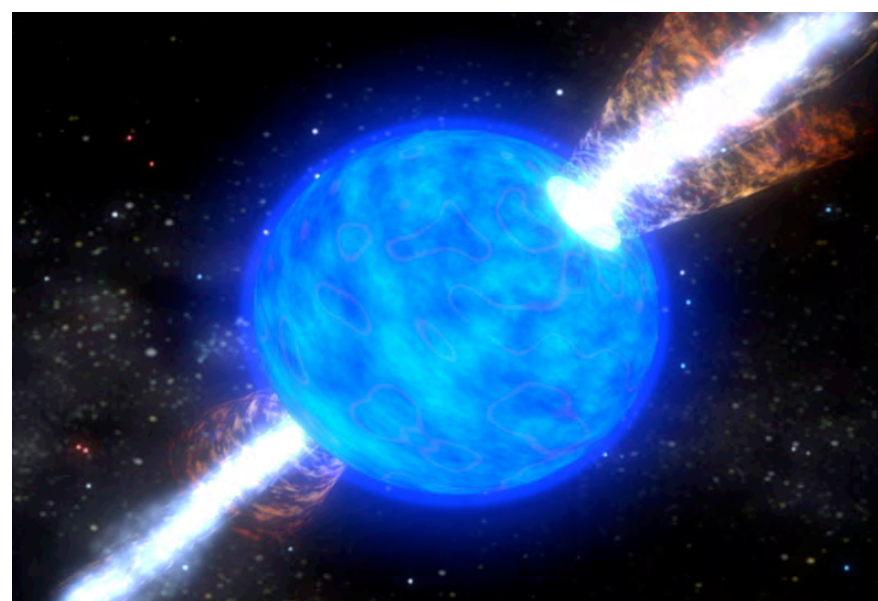
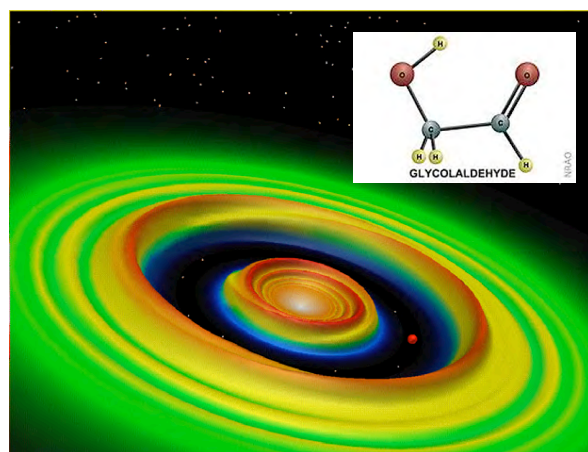
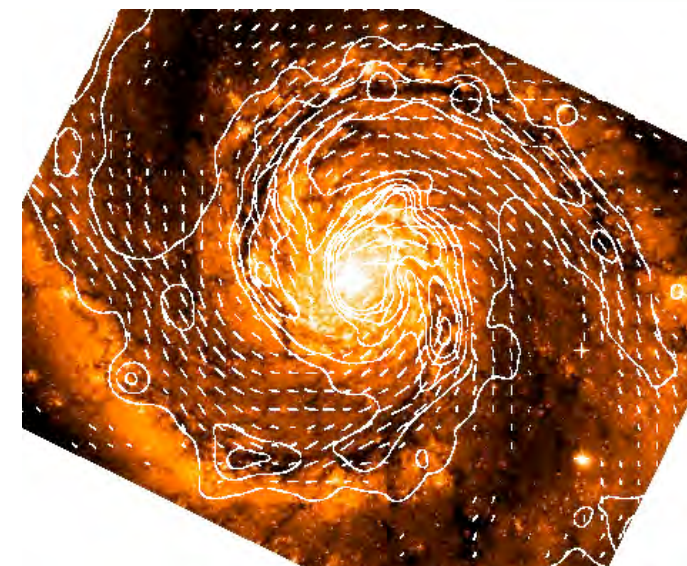
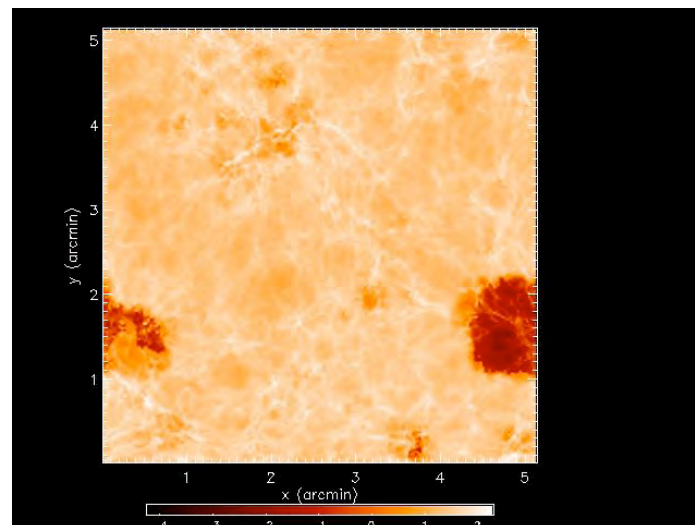
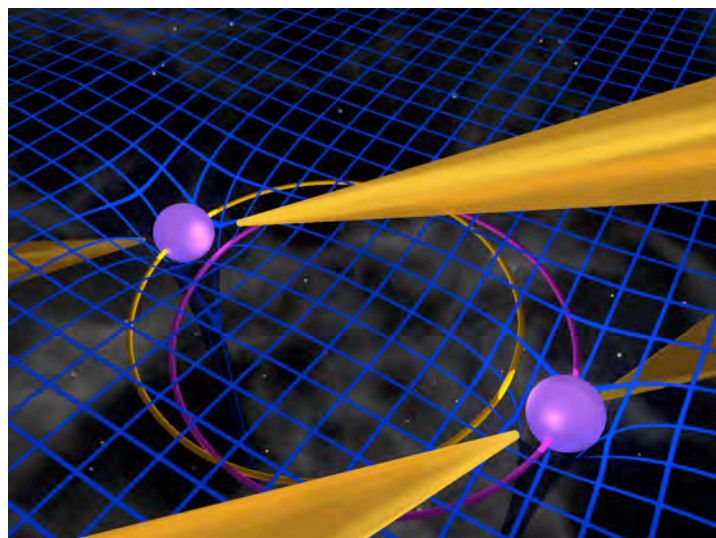
Chris Carilli & Steve Rawlings,
New Astronomy Reviews,
Vol.48, Elsevier, Dec. 2004



http://www.skads-eu.org/p/SKA_SciBook.php

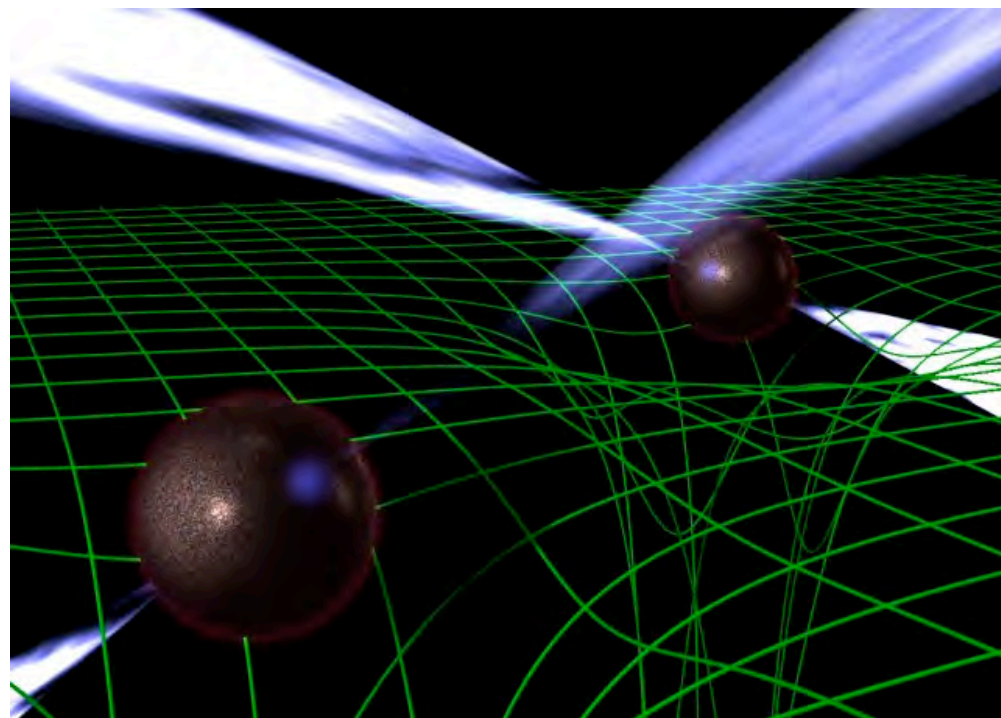


SKA Key Science





Strong Field Tests of Gravity

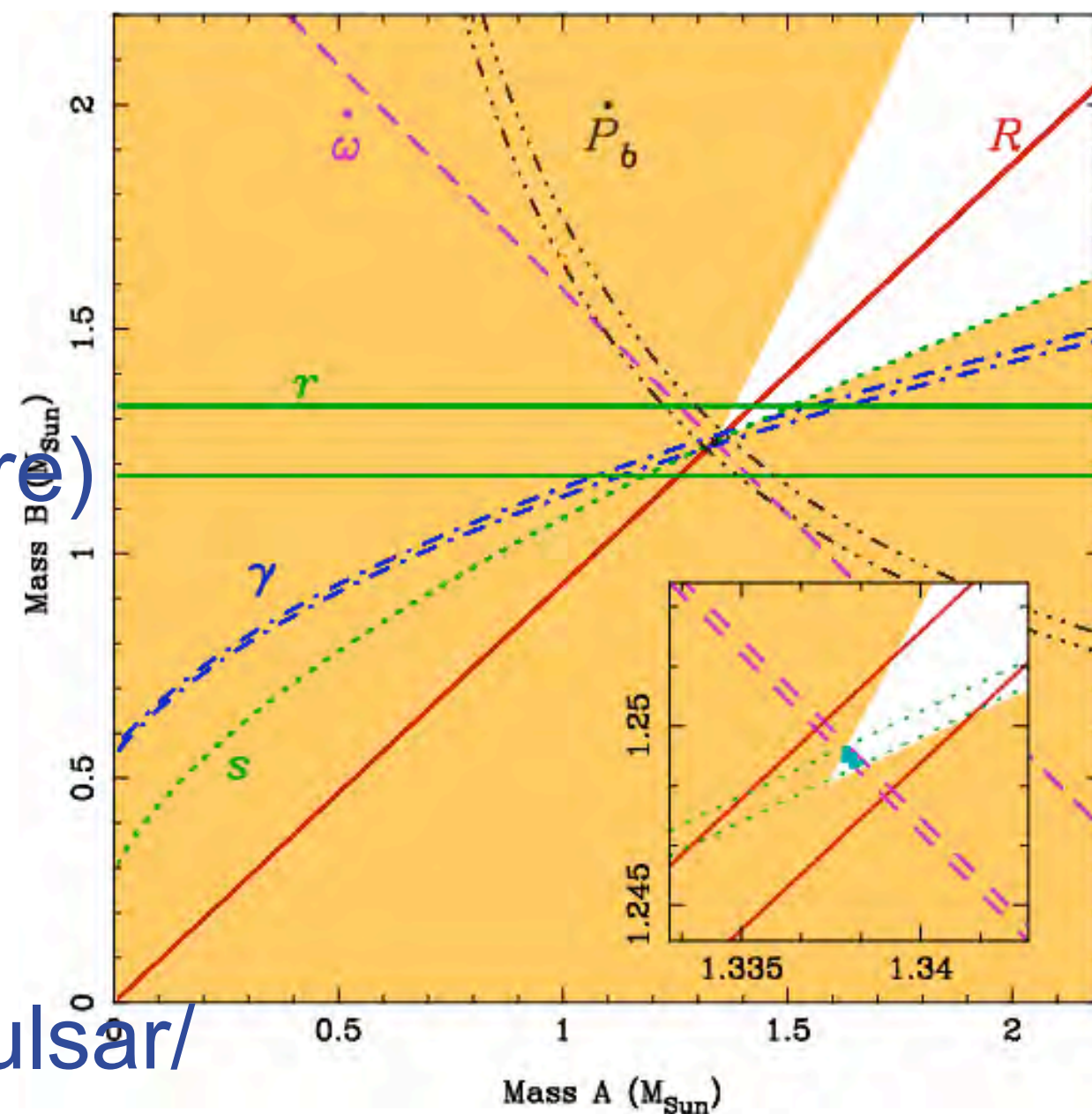


Binary orbit permits determination of masses

Relativistic effects permit (re)
determination of masses.

ALL MUST AGREE

<http://www.jb.man.ac.uk/~pulsar/>

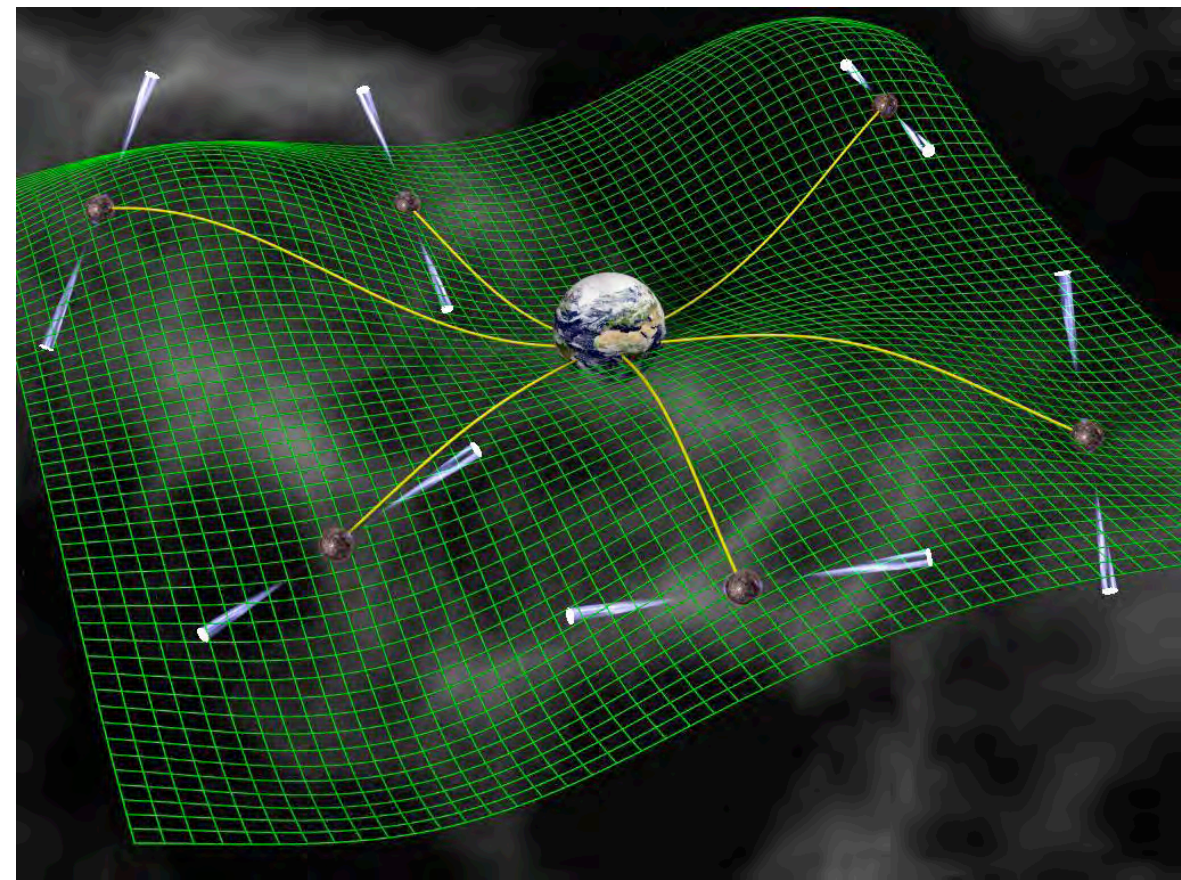




Strong Field Tests of Gravity



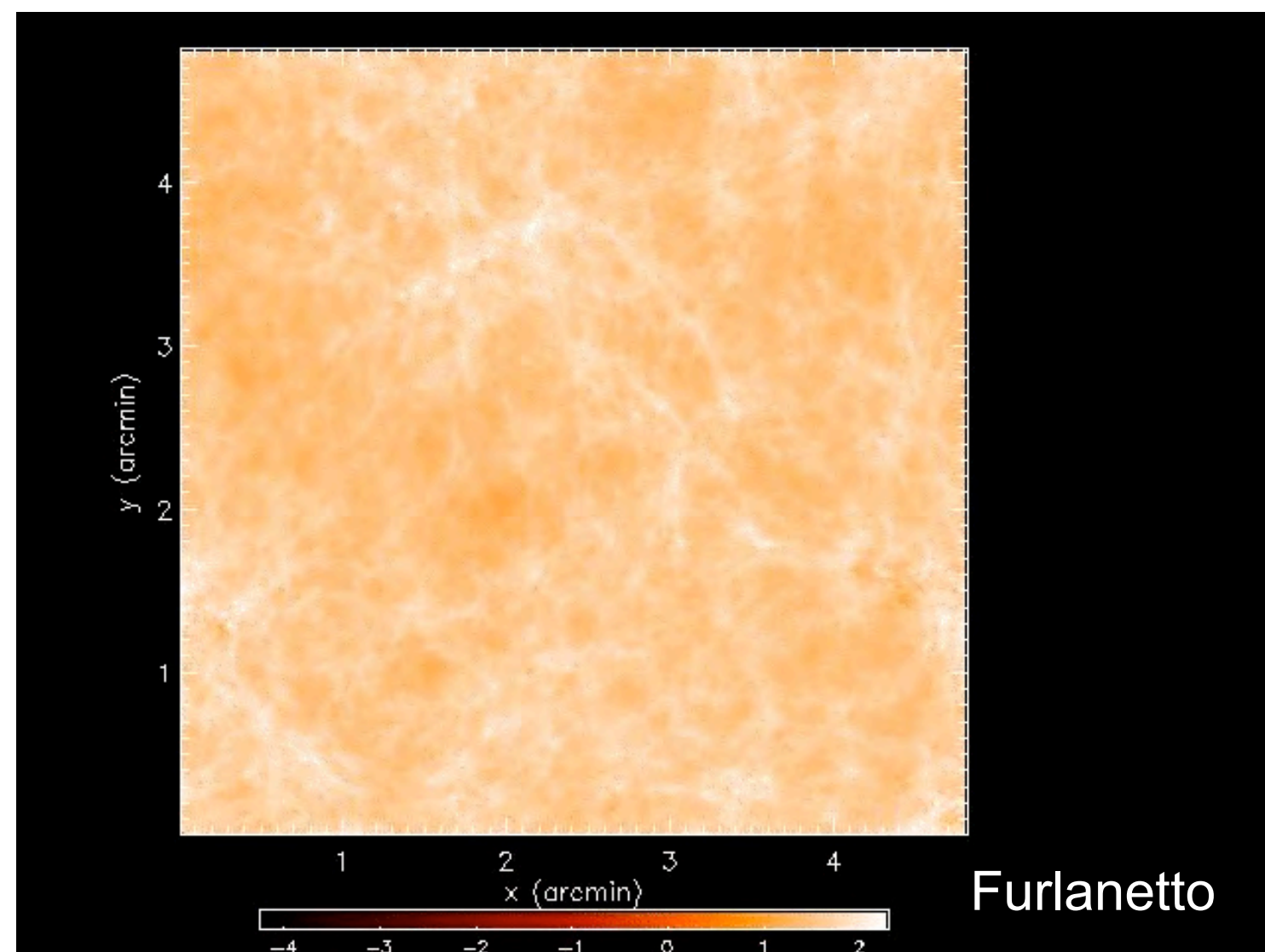
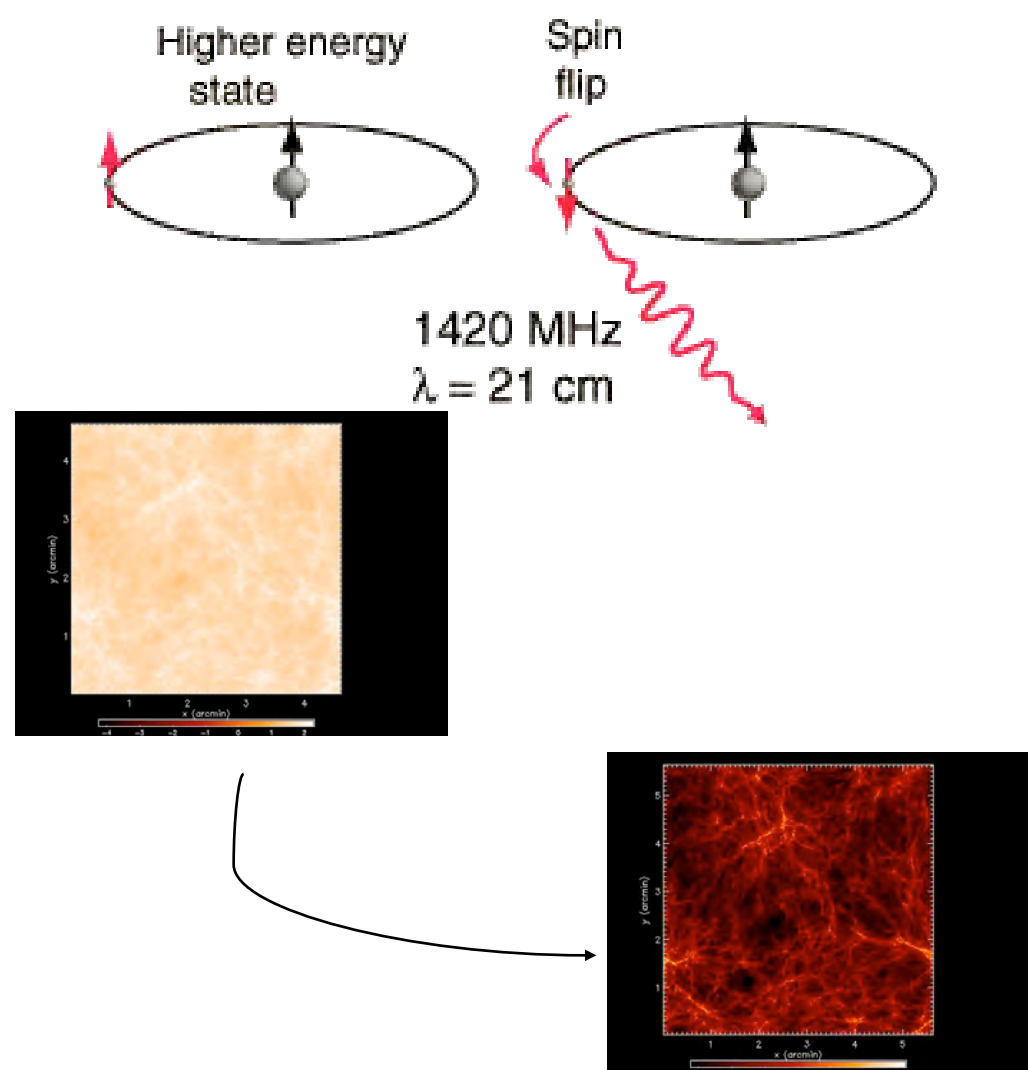
- Large surveys will find exotic binaries
 - ~20 000 pulsars in the galaxy
 - Edge-on Pulsar – Black-hole binary (at least one)
 - Probe eg. Frame dragging
- Pulsar timing array
 - Gravitational wave background





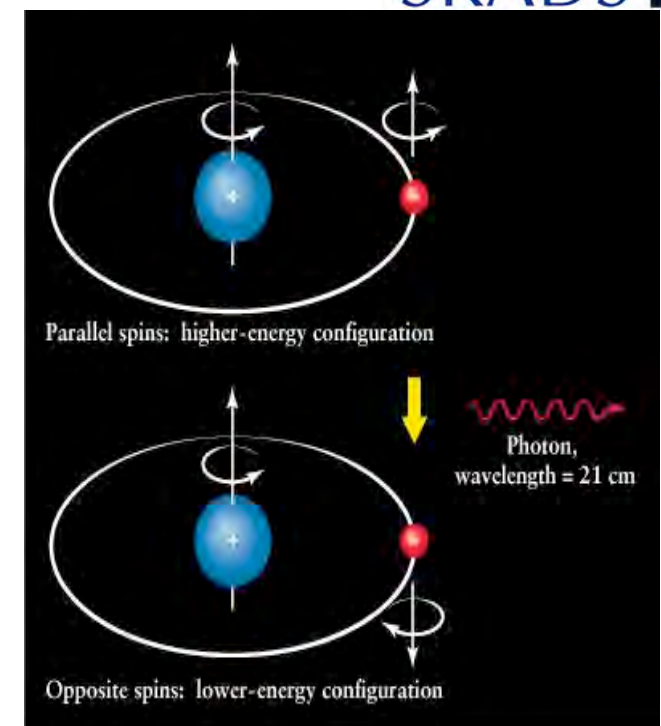
Probing the Dark Ages

- When did the first luminous objects form?
- How did they form and over what period of time?
- SKA will detect the **Epoch of Reionisation** and map the evolution history of the first luminous objects

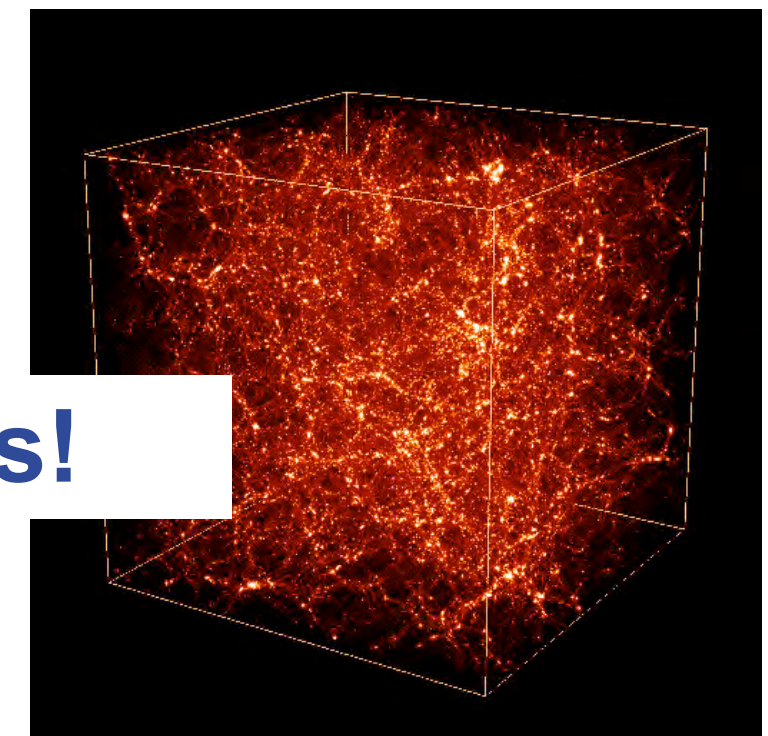




Large Scale Structure

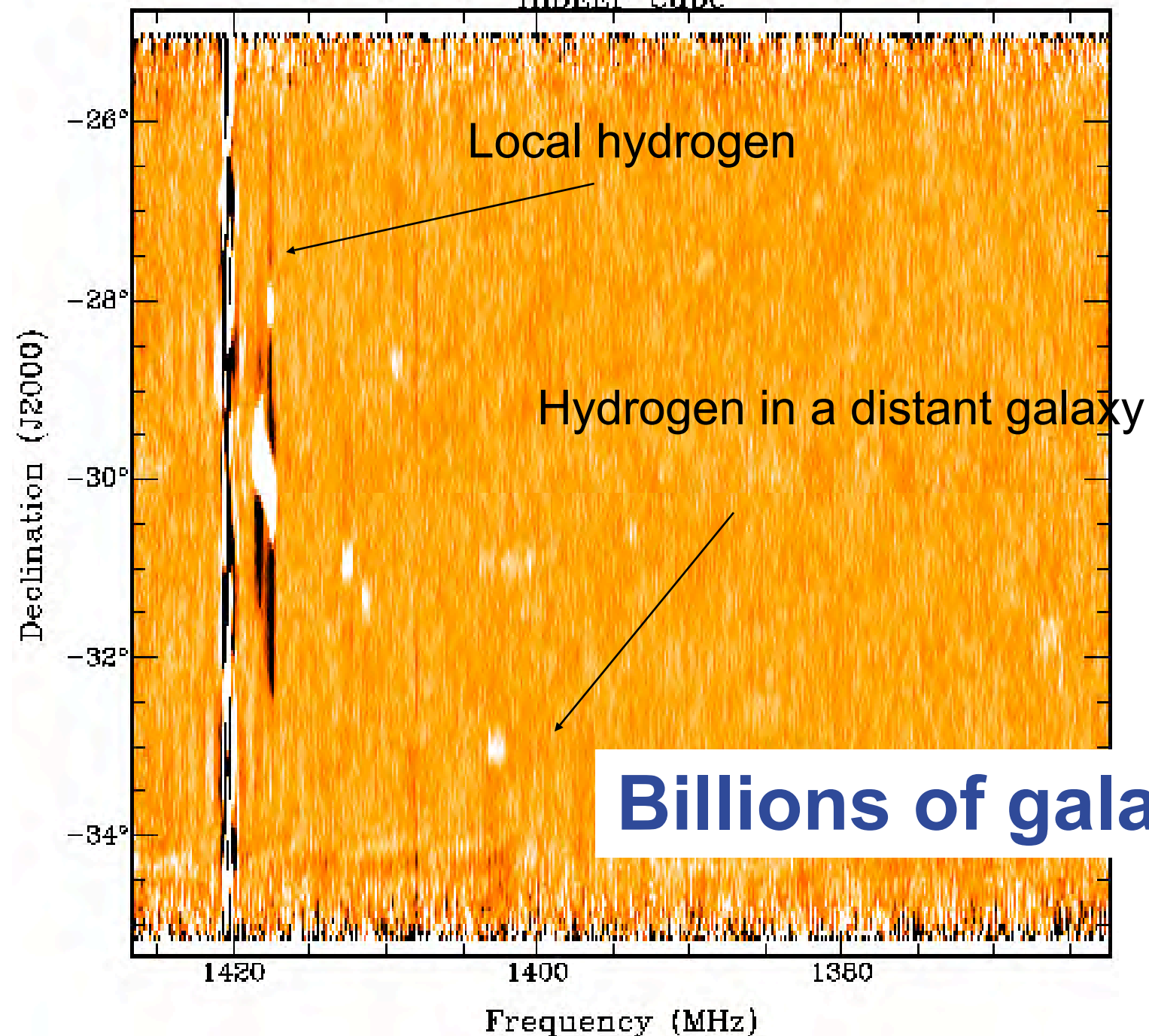


b



Ra: 13^h 37^m 54.94^s (J2000)

HIDEEP Cube



Billions of galaxies!



Dark Energy Experiments

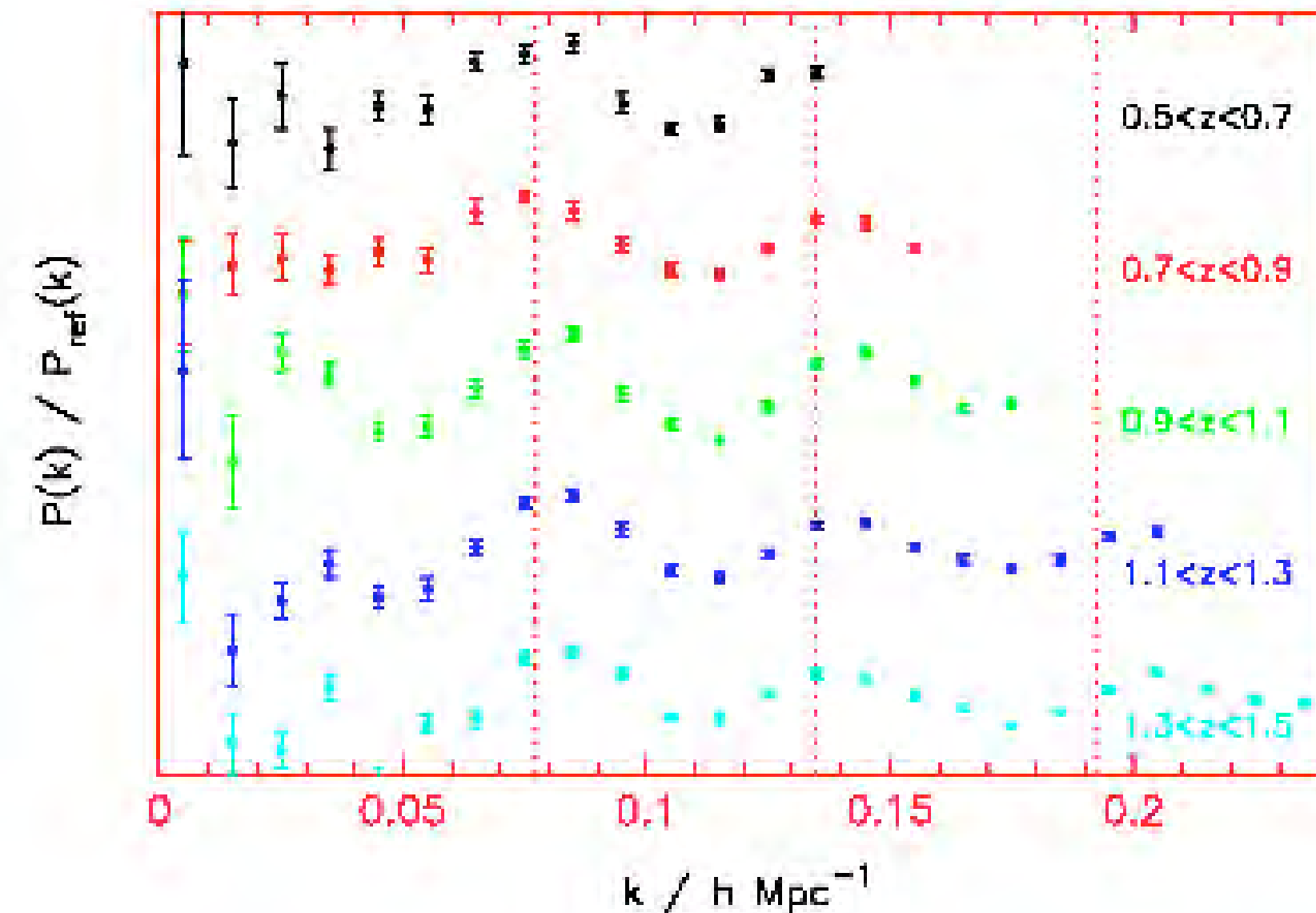


- Baryonic Acoustic Oscillations
 - 10^9 galaxy redshift survey
- Cosmic Shear (weak lensing)
 - 10^{10} galaxy survey
- H_0 with water maser proper motions
- Dark Energy sound speed (CMB cross-correlation)

(venez ce soir !)



BAO in redshift bins

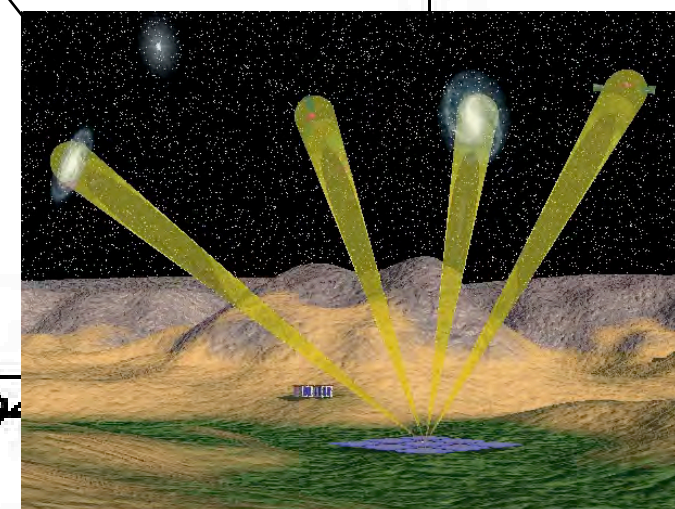
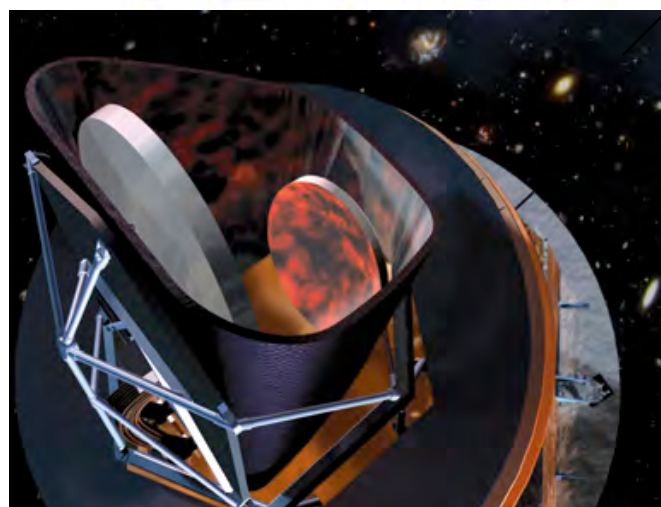
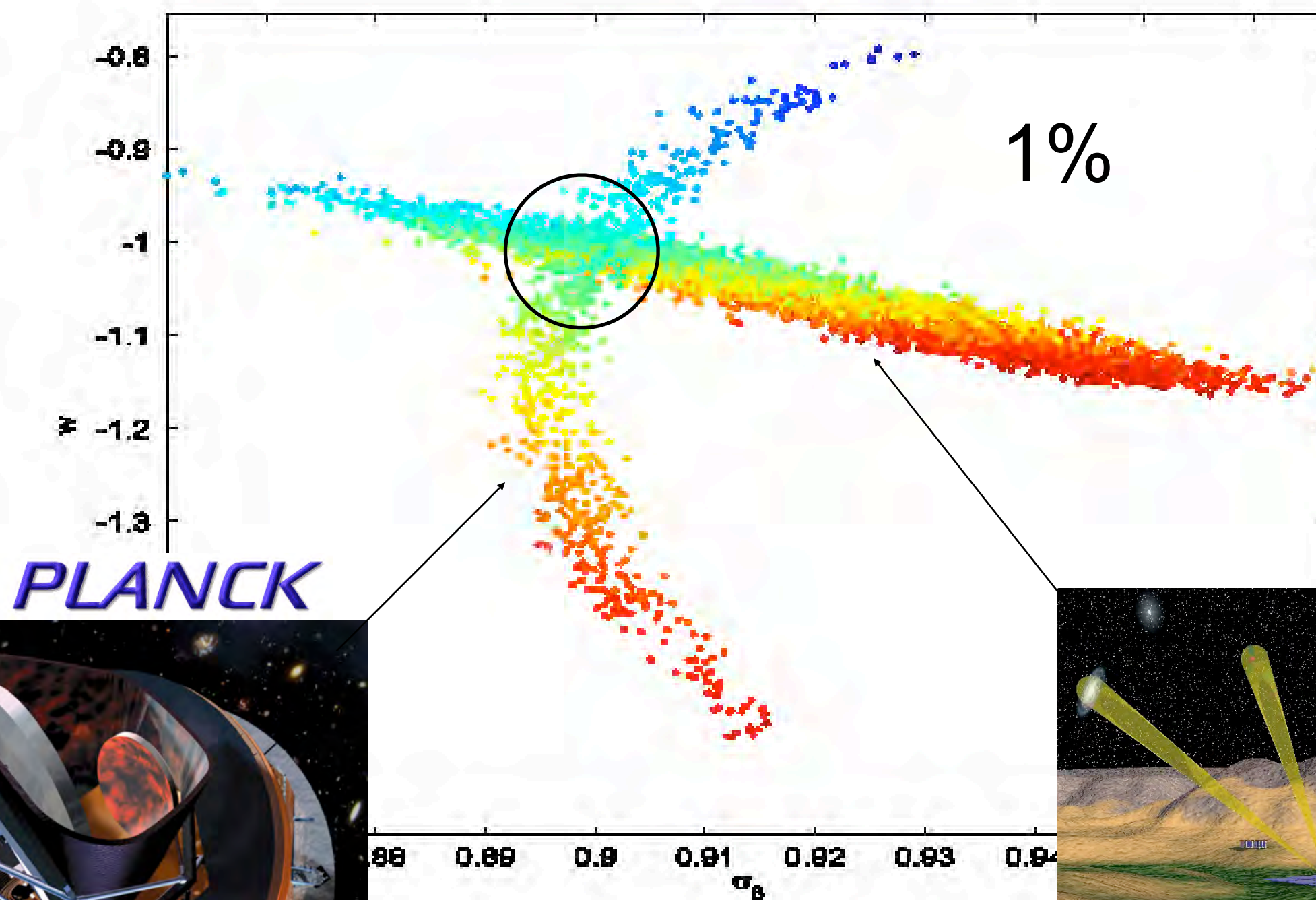


- Improve signal confidence by measuring wiggles in separate redshift bins

Blake et al 2004: example assuming $w=-0.8$, peaks don't line up with CMB peaks (vertical lines)



Complementarity with Planck





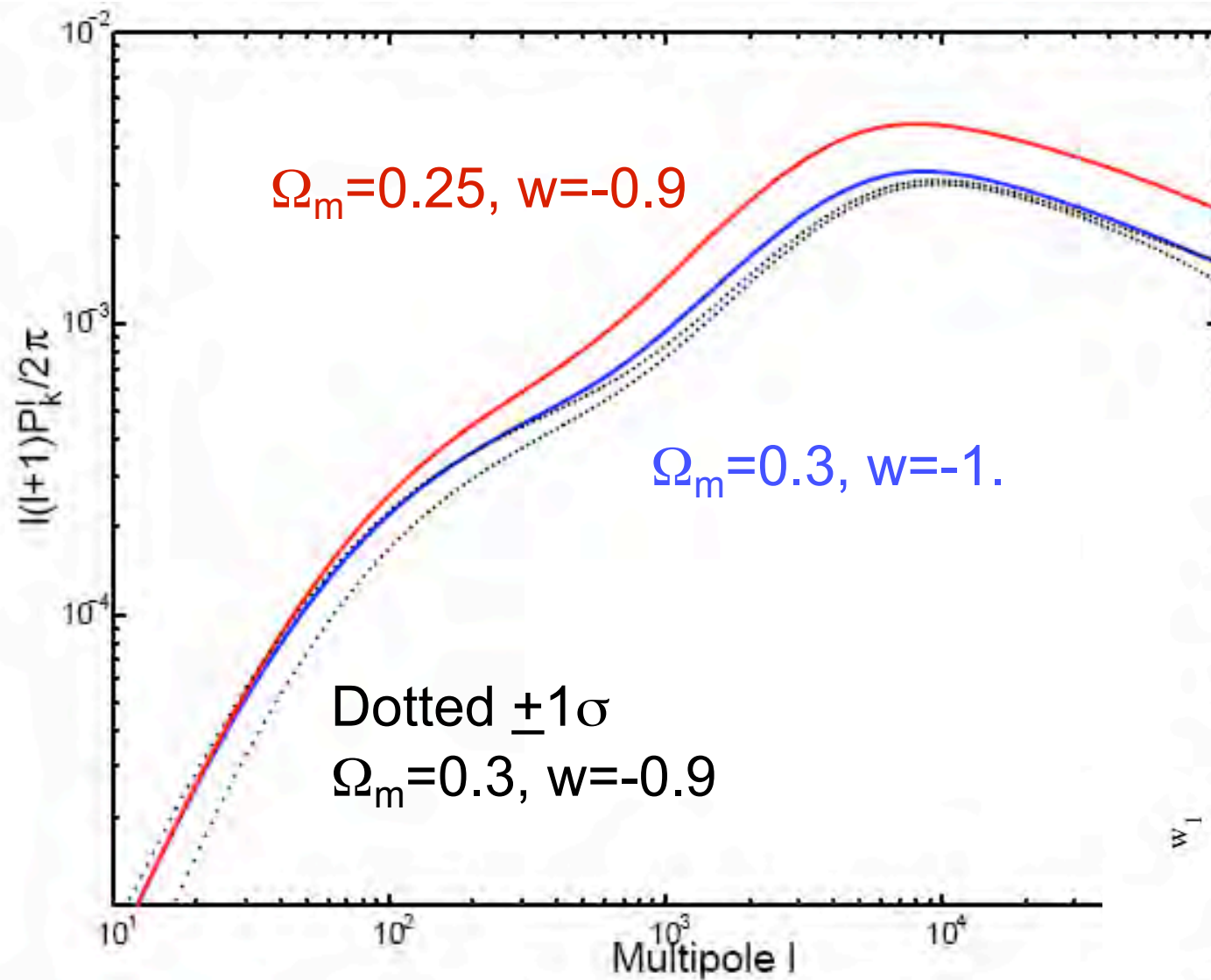
Cosmic Shear



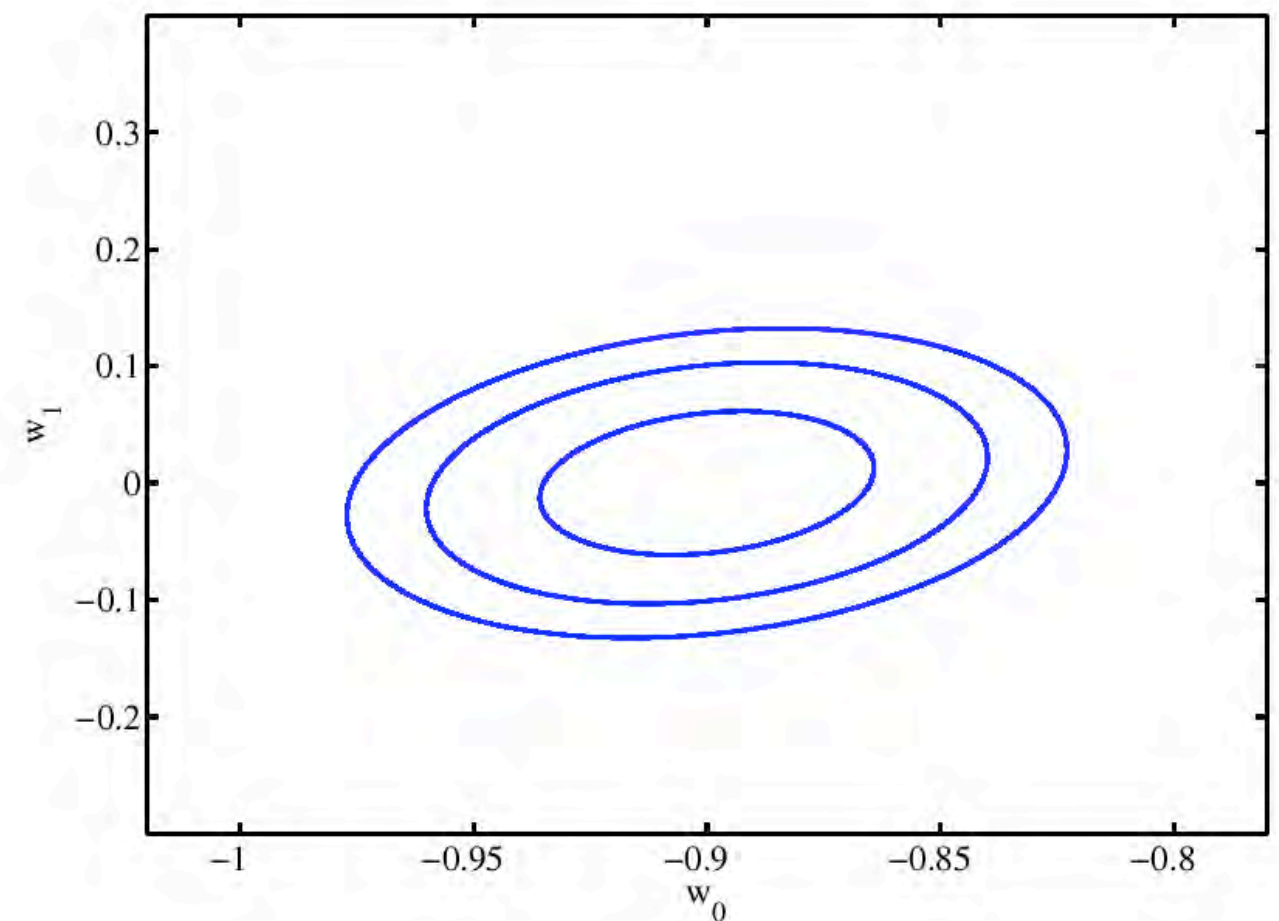
- Integrated gravitational lensing along line-of-sight
 - “weak lensing”
- Requires large statistics
 - SKA continuum survey of 10 Billion galaxies
 - Clean sample
 - Reject star burst galaxies which may be the result of mergers (morphological alignment not the result of cosmic shear)
 - Still have a large sample with SKA
 - Improve result with analysis in redshift bins
 - Redshifts from SKA HI survey



SKA Weak Lensing



Could improve with redshift bins

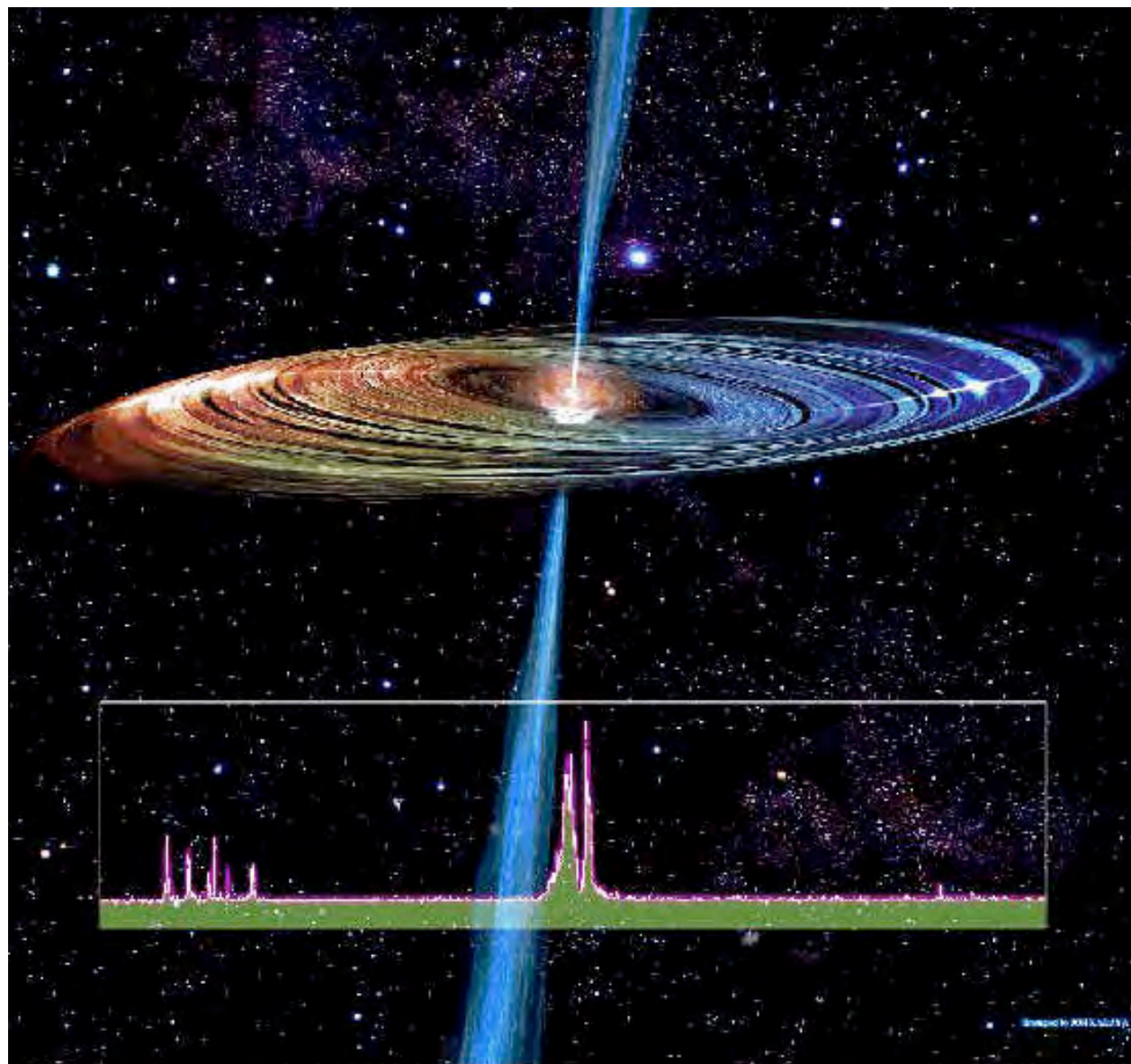


68%, 95%, 99% likelihood contours

Blake et al 04



Measurement of H_0 with water masers



Case of NGC 4258:
(Greenhill et al, 1995,
Aragon et al 2007)

Water masers at various z
will provide H_0 with 1% precision



Proper motions of Water Masers

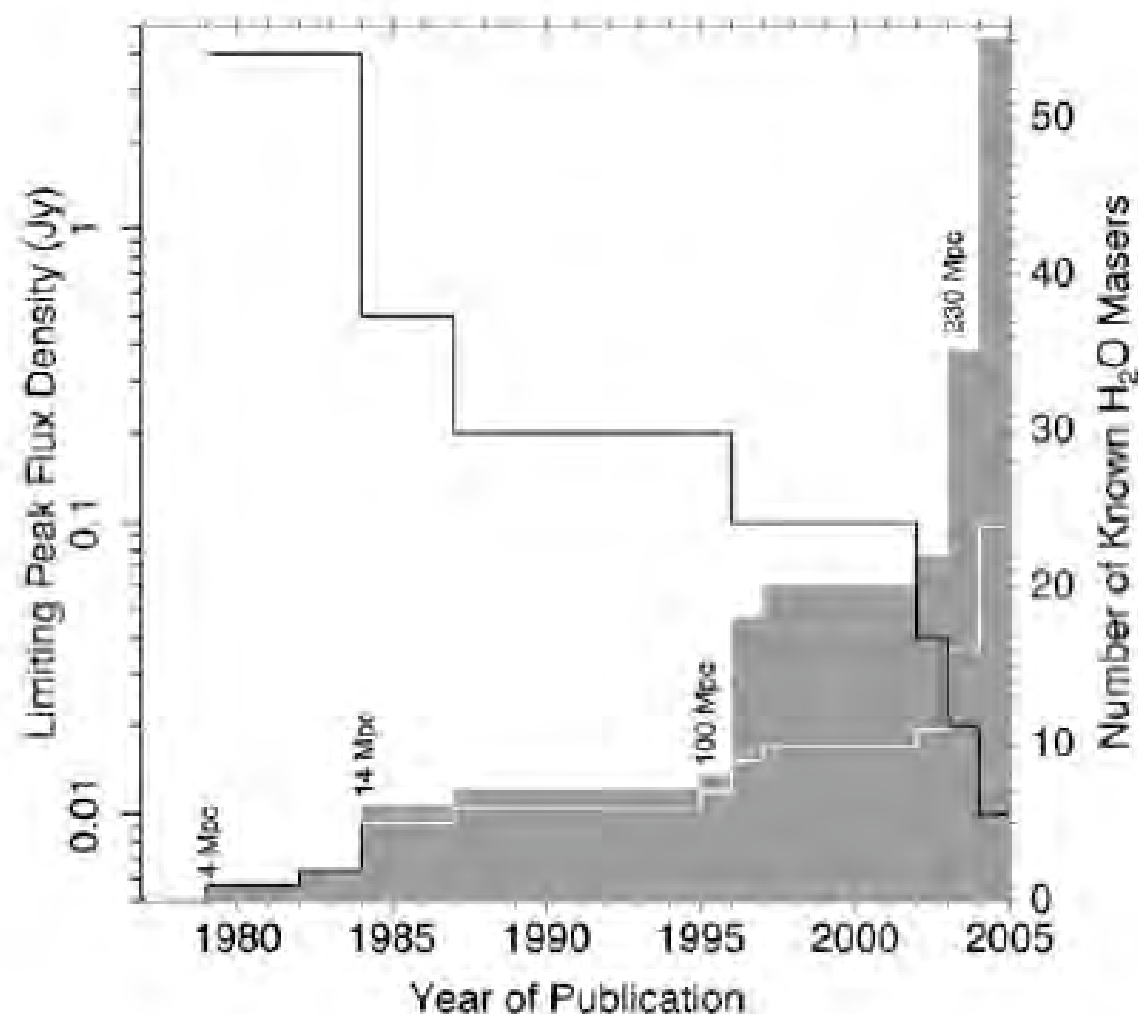


50 masers known today
(mainly GBT data)

For NGC 4258: 3%
precision (proper motions
over 6 yrs with VLBI)

SKA will find ~1000 masers

With ~10% useful for
proper motion
100 masers
→ 1% on H_0



Greenhill 2004



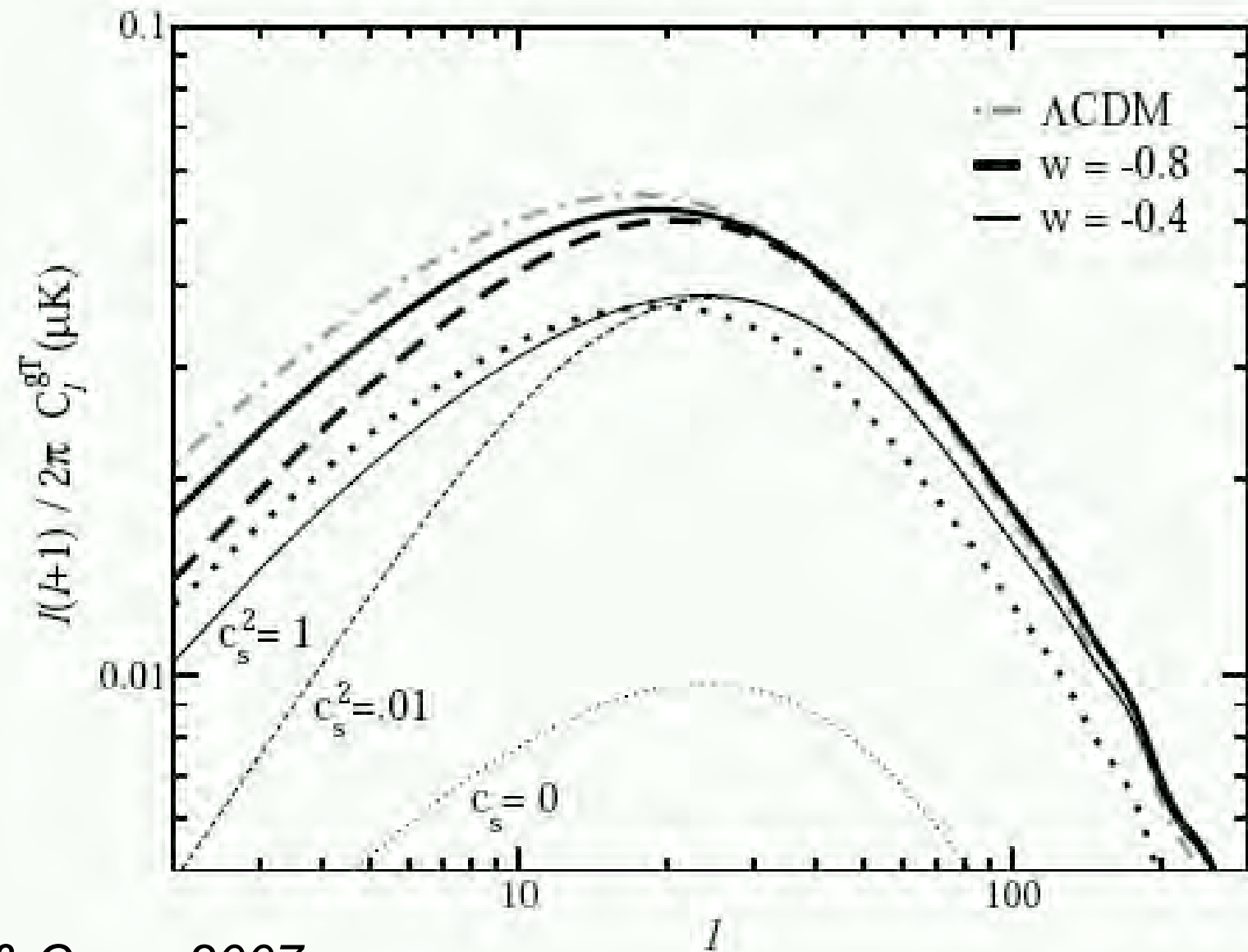
DE sound speed c_s^2



Cross-correlation of CMB
and galaxy overdensities

$0 < z < 2$

Only for $w \neq -1$



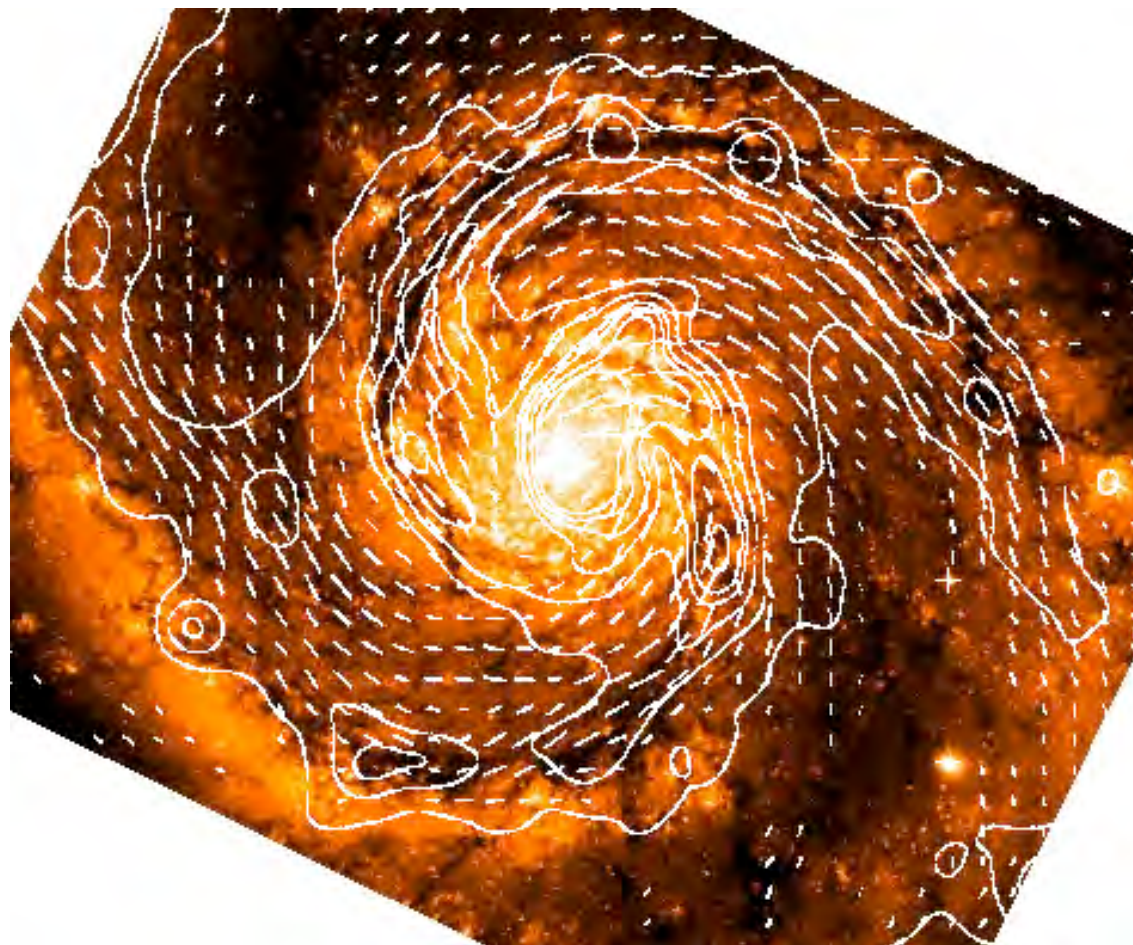
Torres-Rodriguez & Cress 2007



Cosmic Magnetism



- Origin of magnetic fields
 - Dynamo?
 - Primordial?

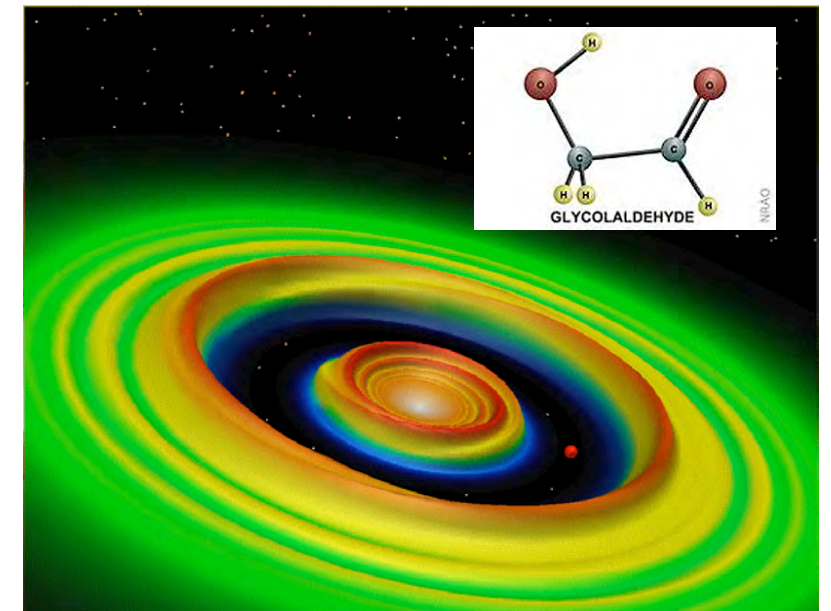




Cradle of Life



- Protoplanetary disks resolved to Earth-like orbits
- Organic molecules
- Extrasolar planets
- Extra terrestrial intelligence







Transients



- Pulsar is a special case of transient phenomena (periodic)
- Giant pulses
- Supernova
- Bursters
- ETI



The Unknown



- New discoveries always result from observations in new parameter space
 - sensitivity
 - spatial resolution
 - spectral resolution
 - polarisation
 - time domain
 - observing speed (multibeaming)
- eg. CMB, pulsars, extra solar planets,...

SKA
improves
all of
these

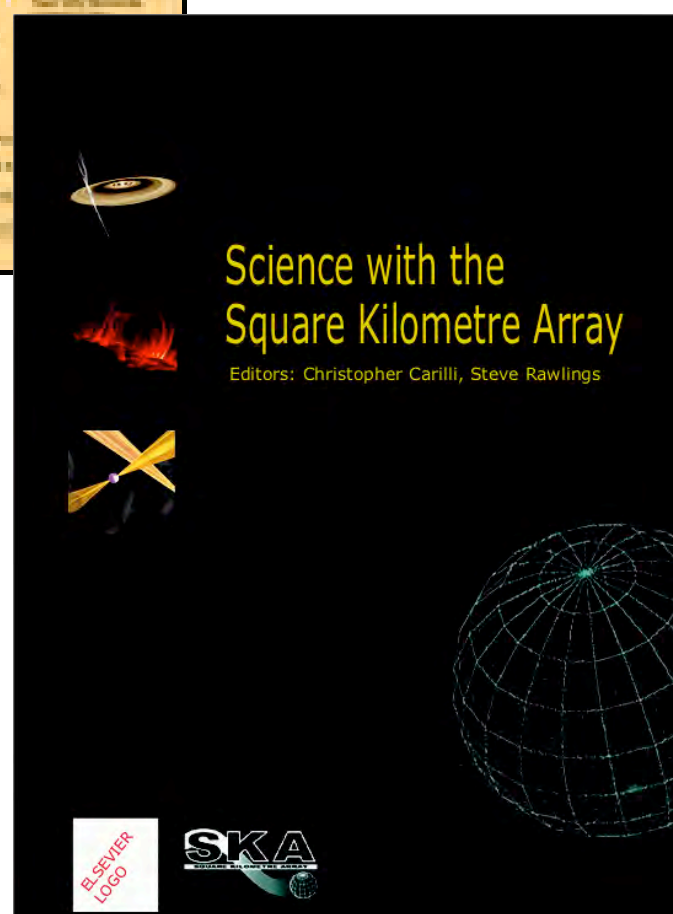


SKA Science Book



Chris Carilli & Steve Rawlings,
New Astronomy Reviews, Vol.48, Elsevier,
Dec. 2004

www.skatelescope.org/pages/science_genScBook.htm





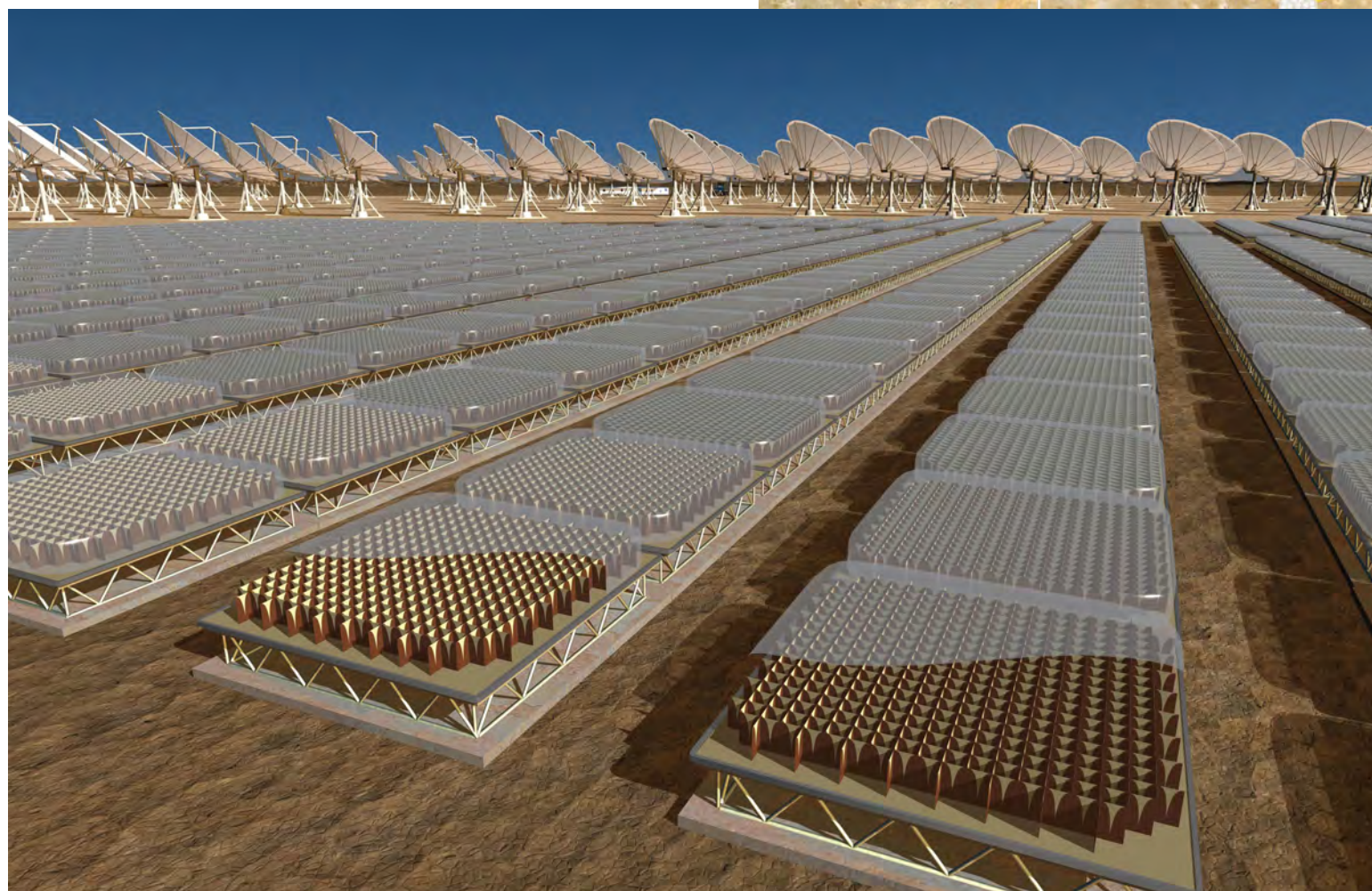
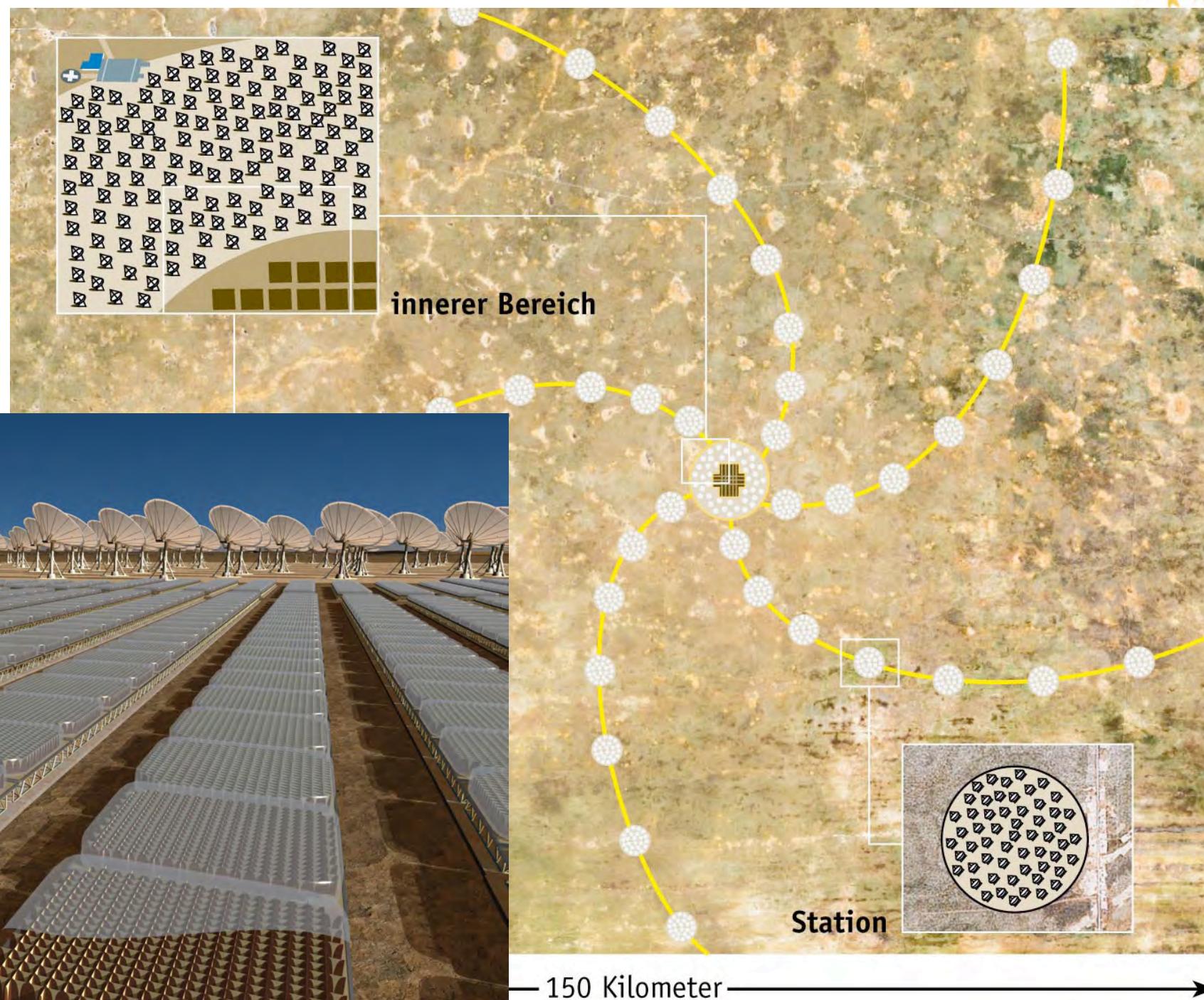
2006: Reference Design



- Very large field of view (~ 10 sq deg)
- Large-D, small-N designs not competitive
 - Canadian LAR, Chinese FAST, Australian SKAMP
- SKA will be a phased array of
 - Dishes 6-15m diameter in ~ 100 stations
 - Dipoles for low frequency
 - Dense phased array for mid frequency
 - **IF SHOWN TO BE FEASIBLE/AFFORDABLE**

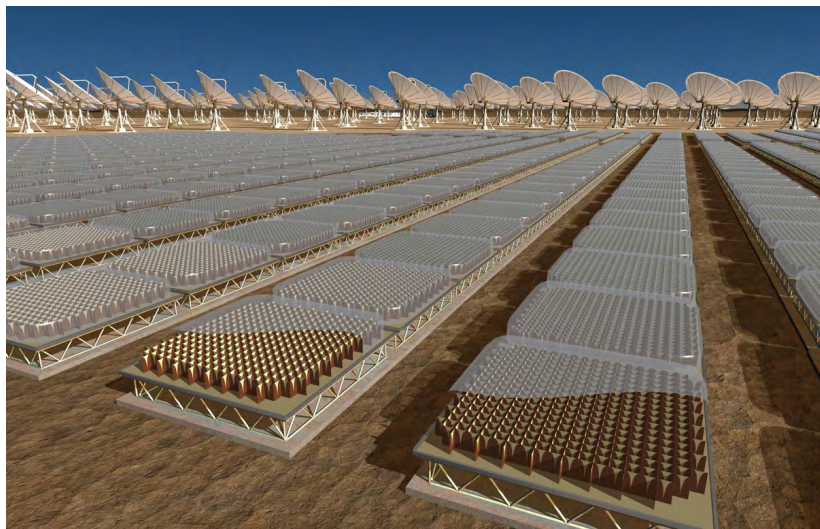


SKA Reference Design (2)

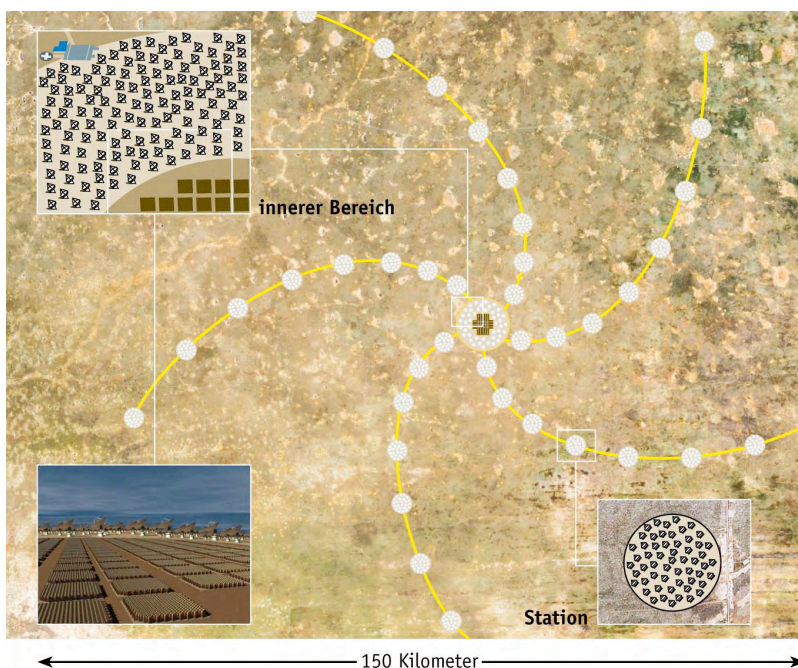




SKA Reference Design (3)

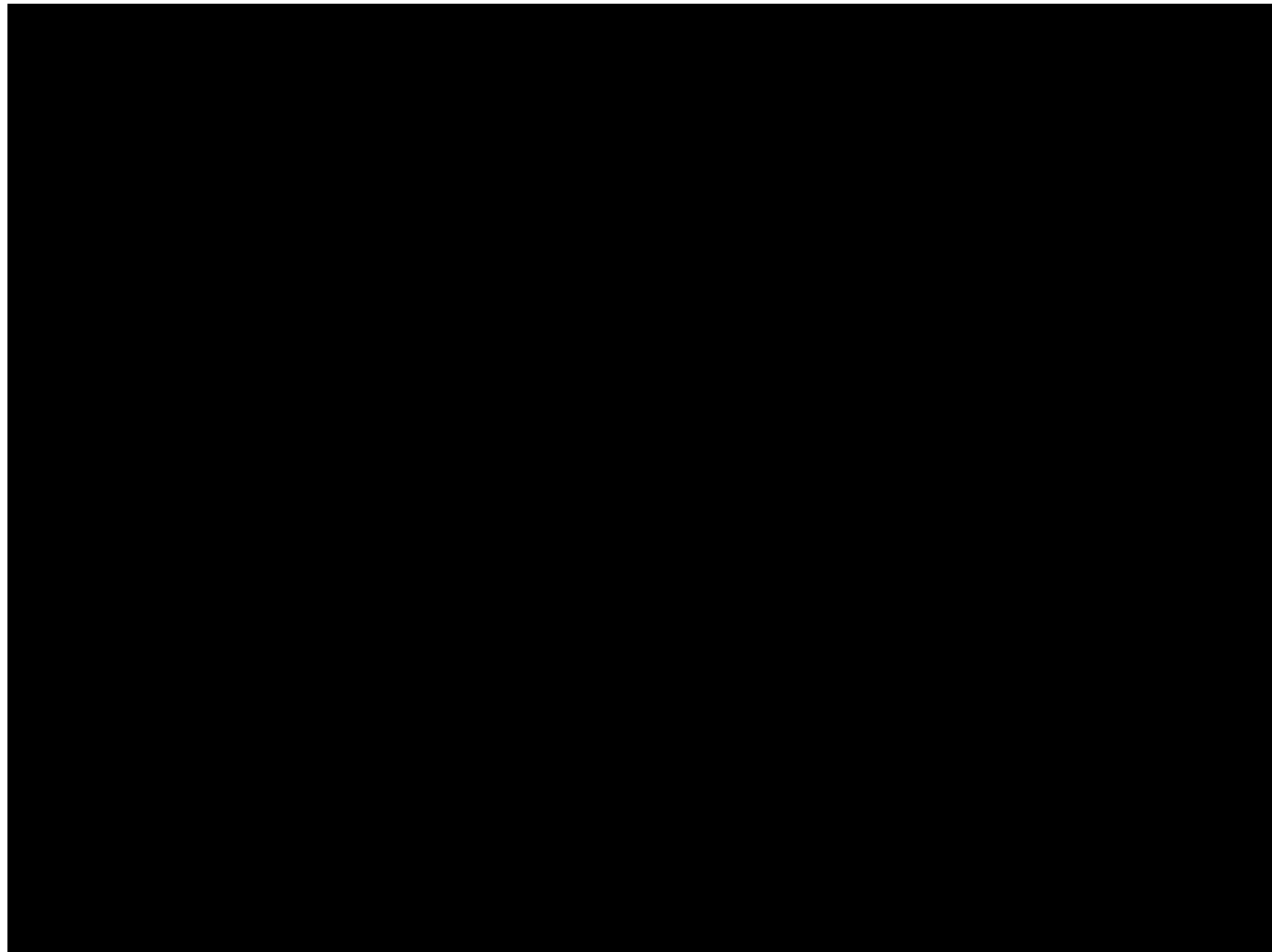


- Inner core (5km) of densely packed phased-array tiles
- Surrounded by paraboloid dishes (~10m diameter)
- Dishes may have multibeam feeds (phased arrays or horn clusters)
- ~200 stations of ~100 dishes each out to a baseline of 3000km





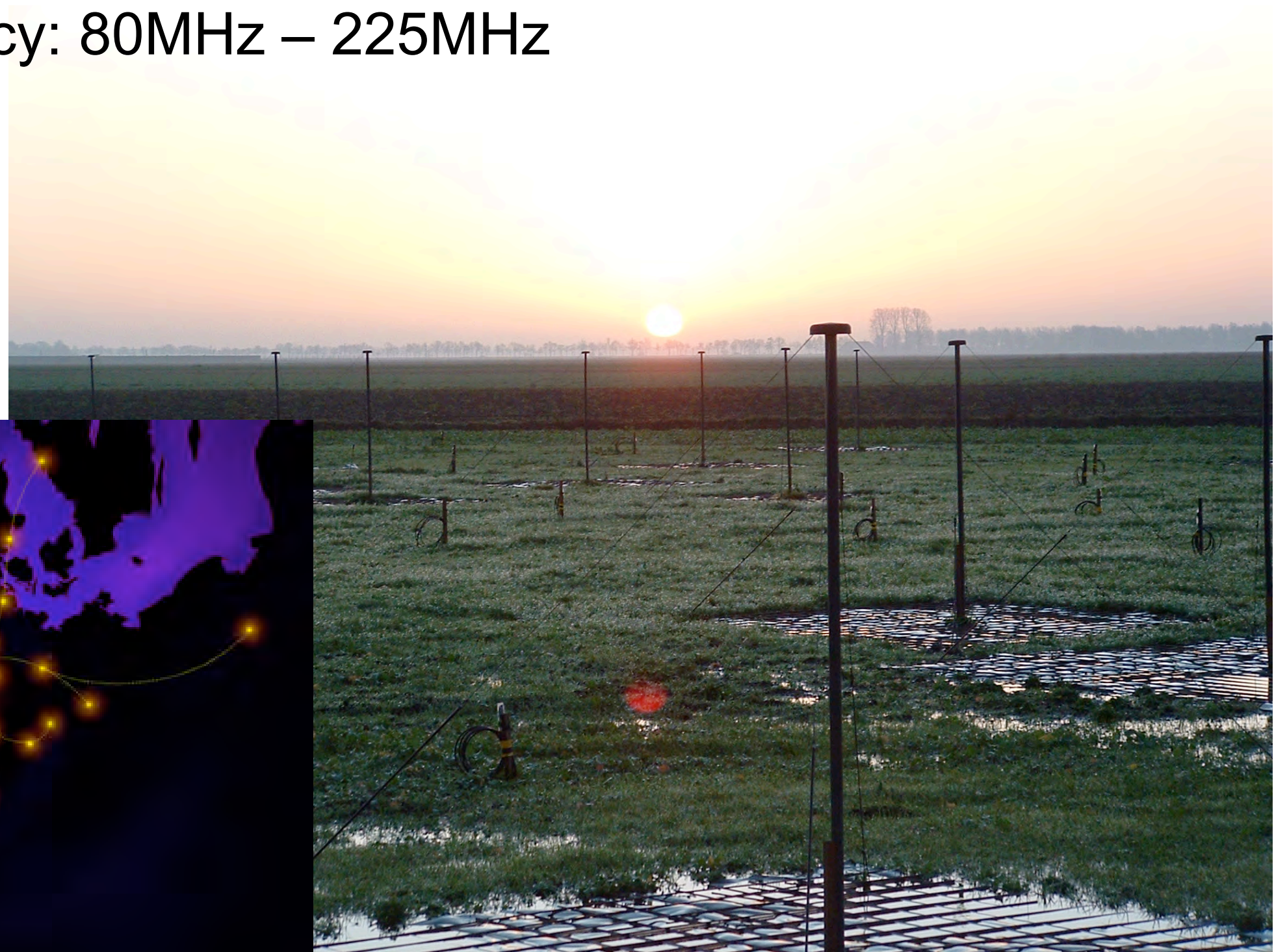
SKA Reference Design





Demonstrator: LOFAR

- Netherlands, with Germany, UK, France, ...
- Low frequency: 80MHz – 225MHz





Demonstrator: Mileura Widefield Array



- Low frequency: (LOFAR competitor)
- USA: Massachusetts Institute of Technology
 - With Australia



Demonstrator: Allen Telescope Array



- Full SKA frequency range (100MHz - ~20GHz)
- Large N, small D (6m)
- N=42 (currently: need ~30 000 for SKA)
- Planned for N=310 (ie. 1% SKA)
- Single pixel, ultra wide band feed

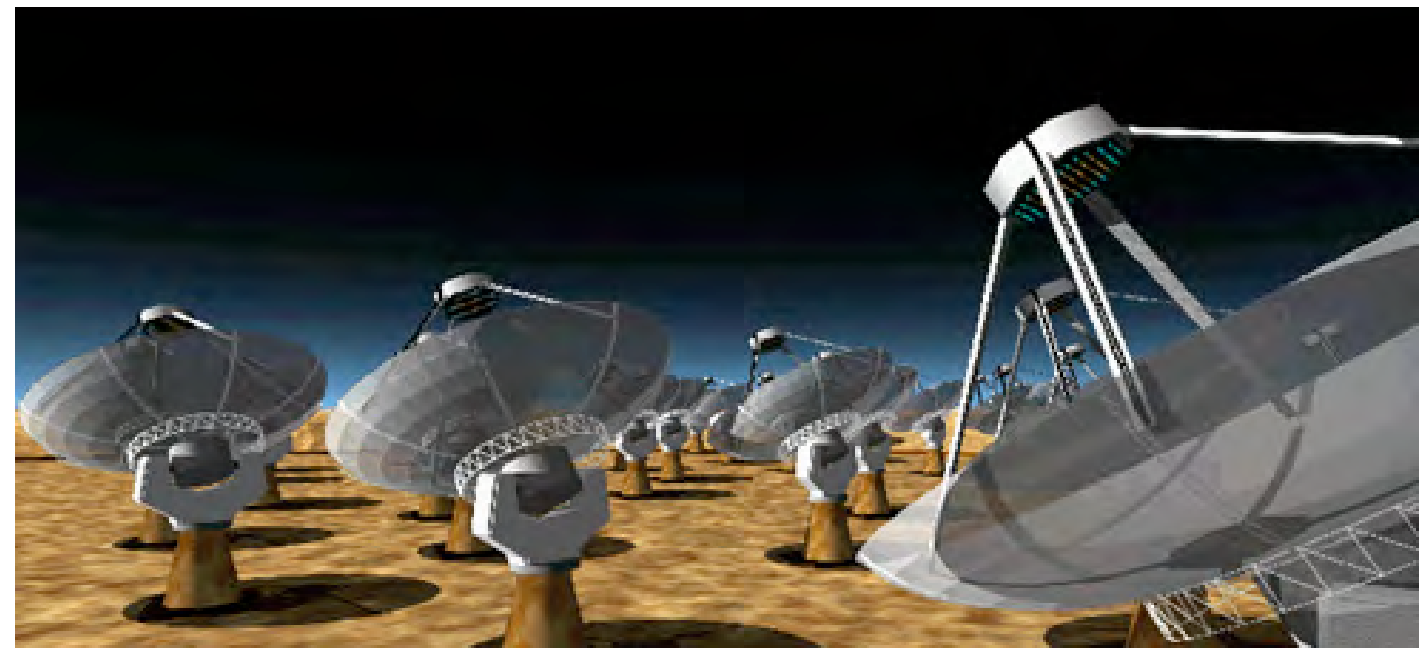




Demonstrator: MIRANdA



- Mileura International Radio Array large-N small-d Array
- ~15m dishes with phased-array feeds
- Partners: Australia and Canada





Demonstrator: KAT & MeerKAT



- South Africa: Karoo Array Telescope
 - 15m dishes with horn clusters
- MeerKAT
 - Possible SKADS Benchmark demonstrator
 - 6m dishes wide band feeds (ATA)
 - Central aperture-plane phased-array





Worldwide SKA efforts

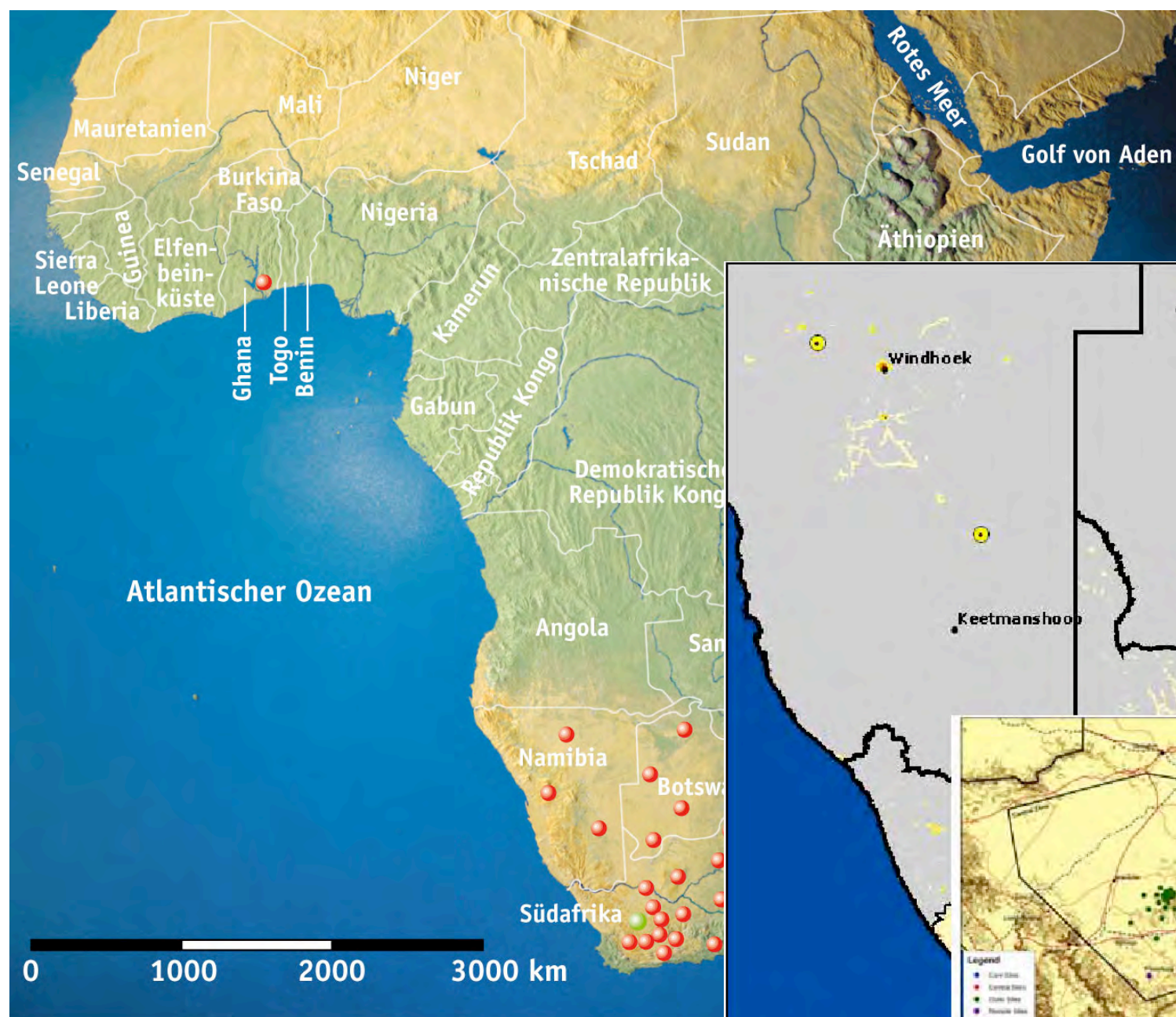


- Europe
 - LOFAR
 - Square Kilometre Array Design Studies
 - 4 year study, 38MEuro (10MEuro from EU Framework Programme 6)
 - EMBRACE demonstrator at Westerbork and Nançay
- Australia & Canada
 - AU\$56M announced in 2007 Australian budget
 - MIRANdA demonstrator
- South Africa
 - Karoo Array Telescope and MeerKAT
 - Over US\$200M confirmed by SA gov't for construction, infrastructure, including high capacity network to Karoo region.
- USA
 - Allen Telescope Array
 - Technology Demonstrator Programme (proposed)

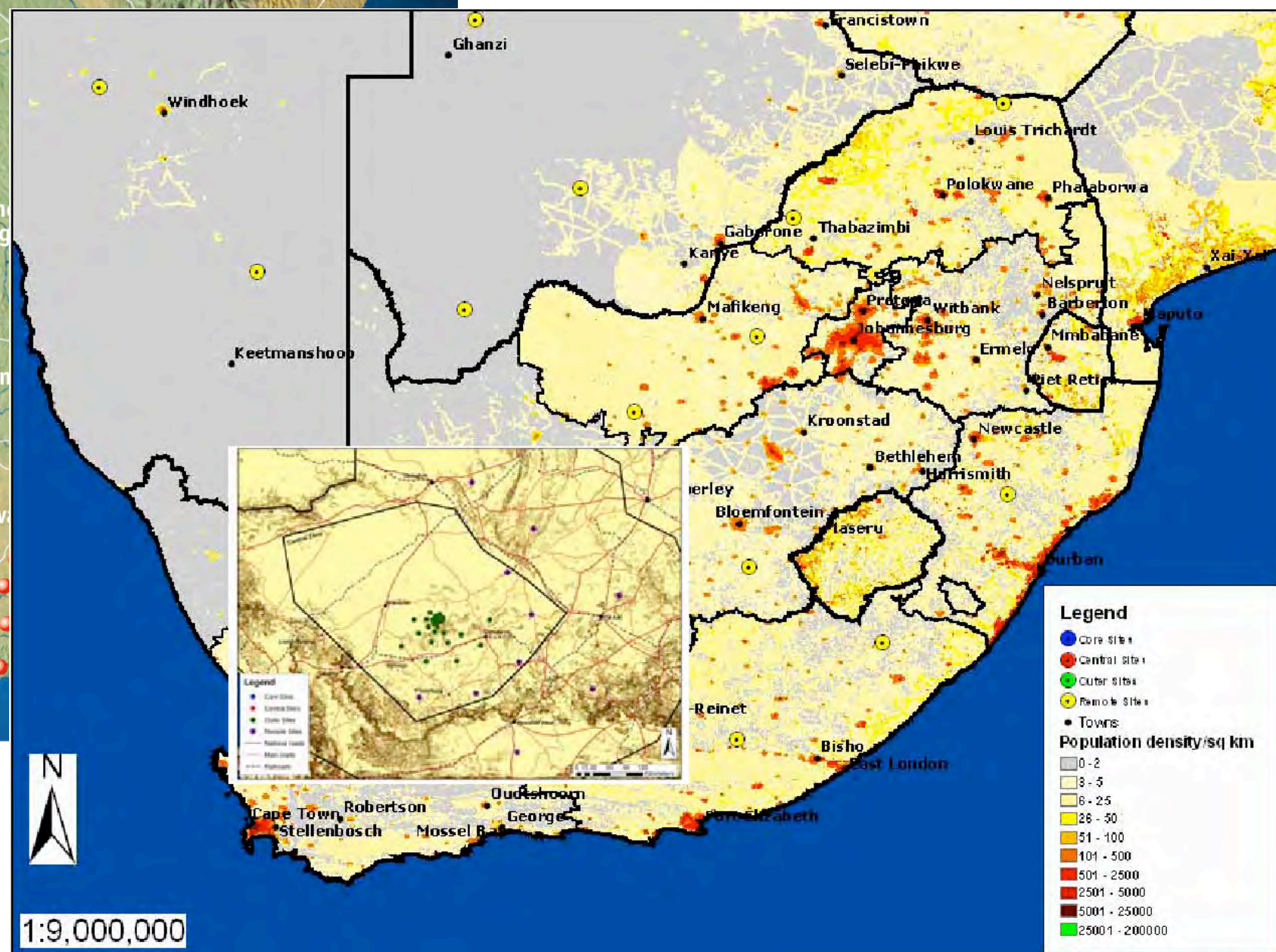
<http://www.skads-eu.org>



candidate site: South Africa

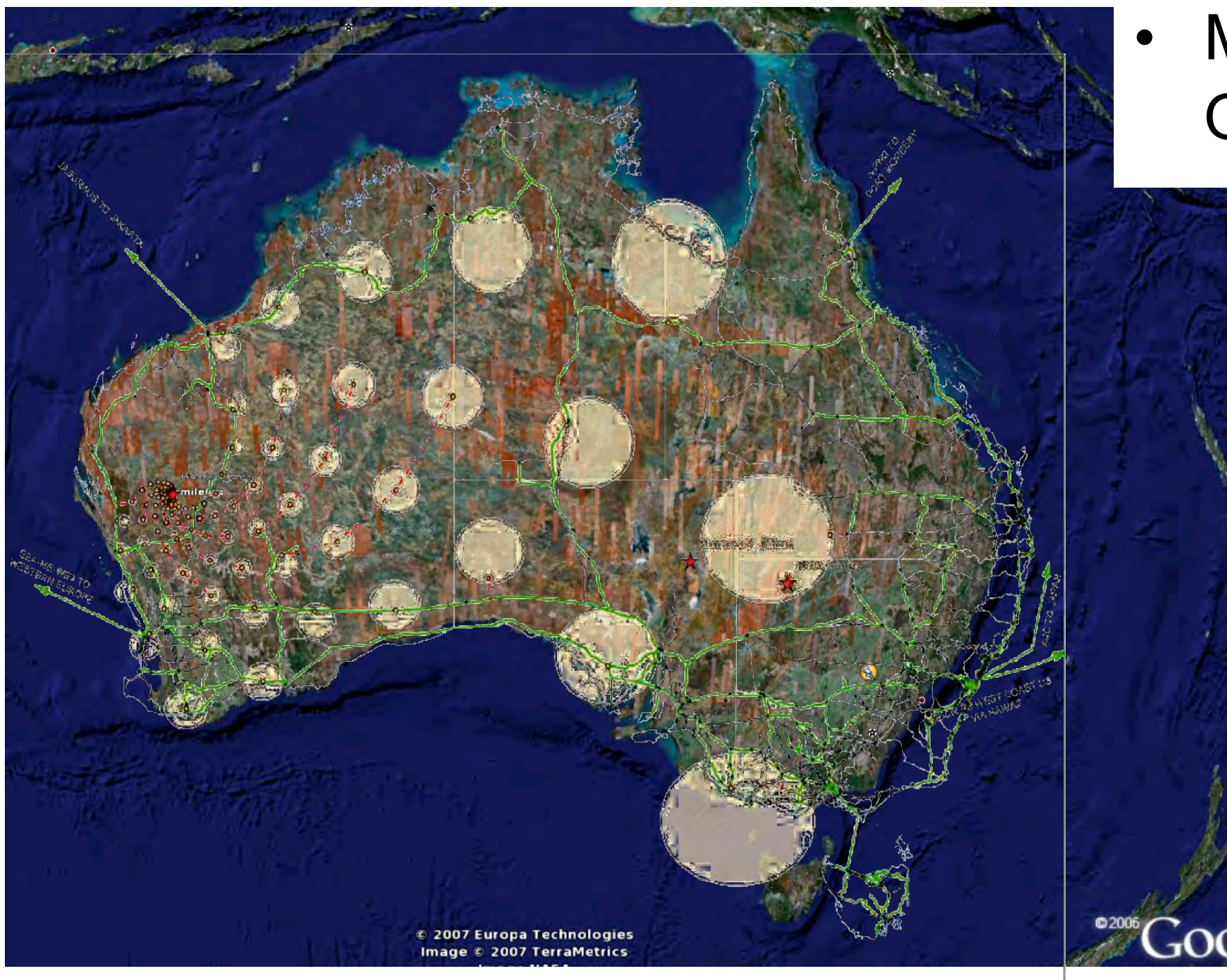


- Karoo radio quiet zone





Candidate site: Australia



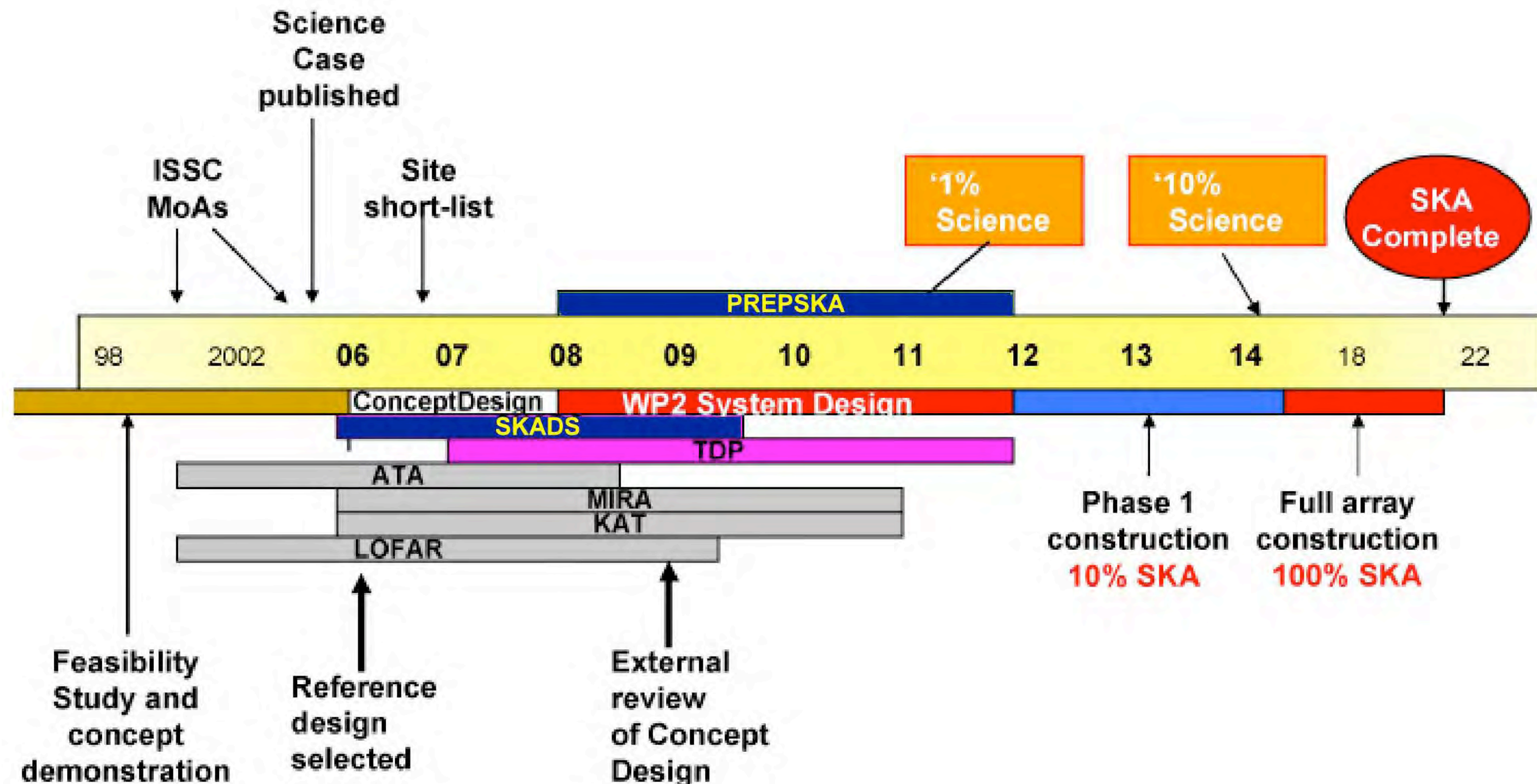
- Mileura Radio Quiet Zone



SKA Timeline



<http://www.skatelescope.org>

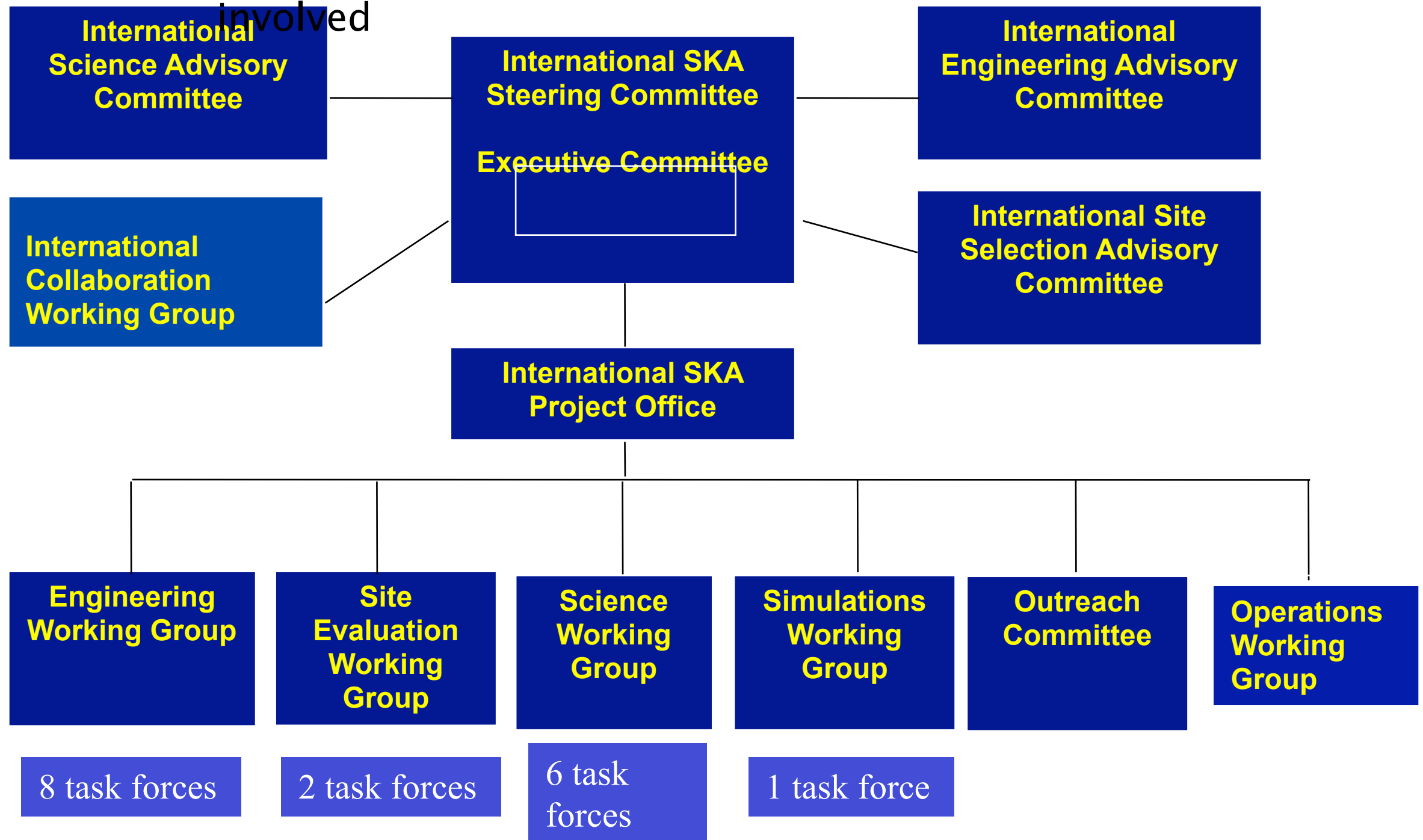




SKA Governance



SKA was “born global”; >50 institutes in 17 countries actively involved





SKA Design Studies

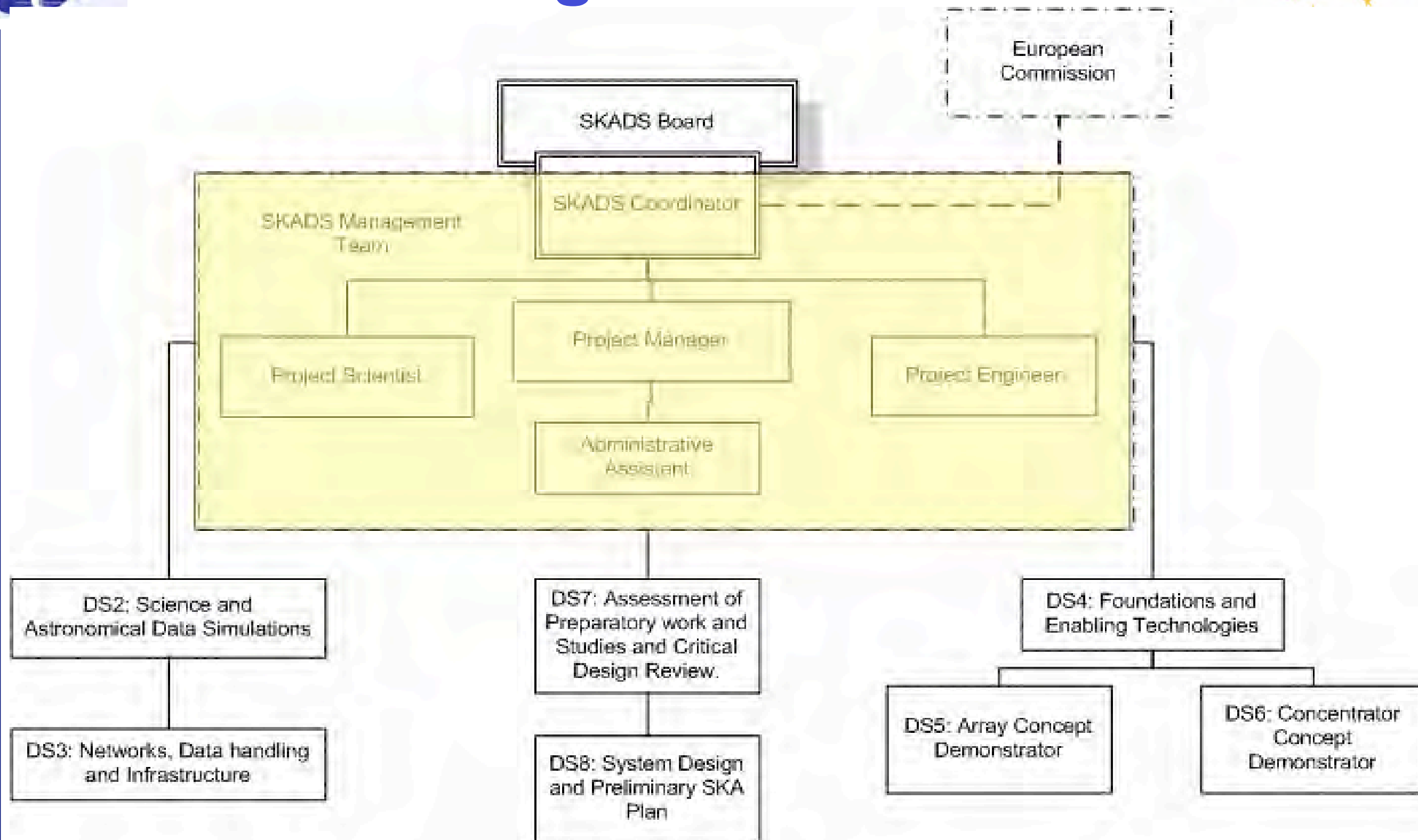


- Square Kilometre Array Design Studies
 - 27 institutes in 13 countries
 - 38MEuro (including matching funds and EU funds)
 - Detailed design and costing, including signal transport, processing requirements, construction costs,...
 - www.skads.eu.org/p/memos.php

<http://www.skads-eu.org>

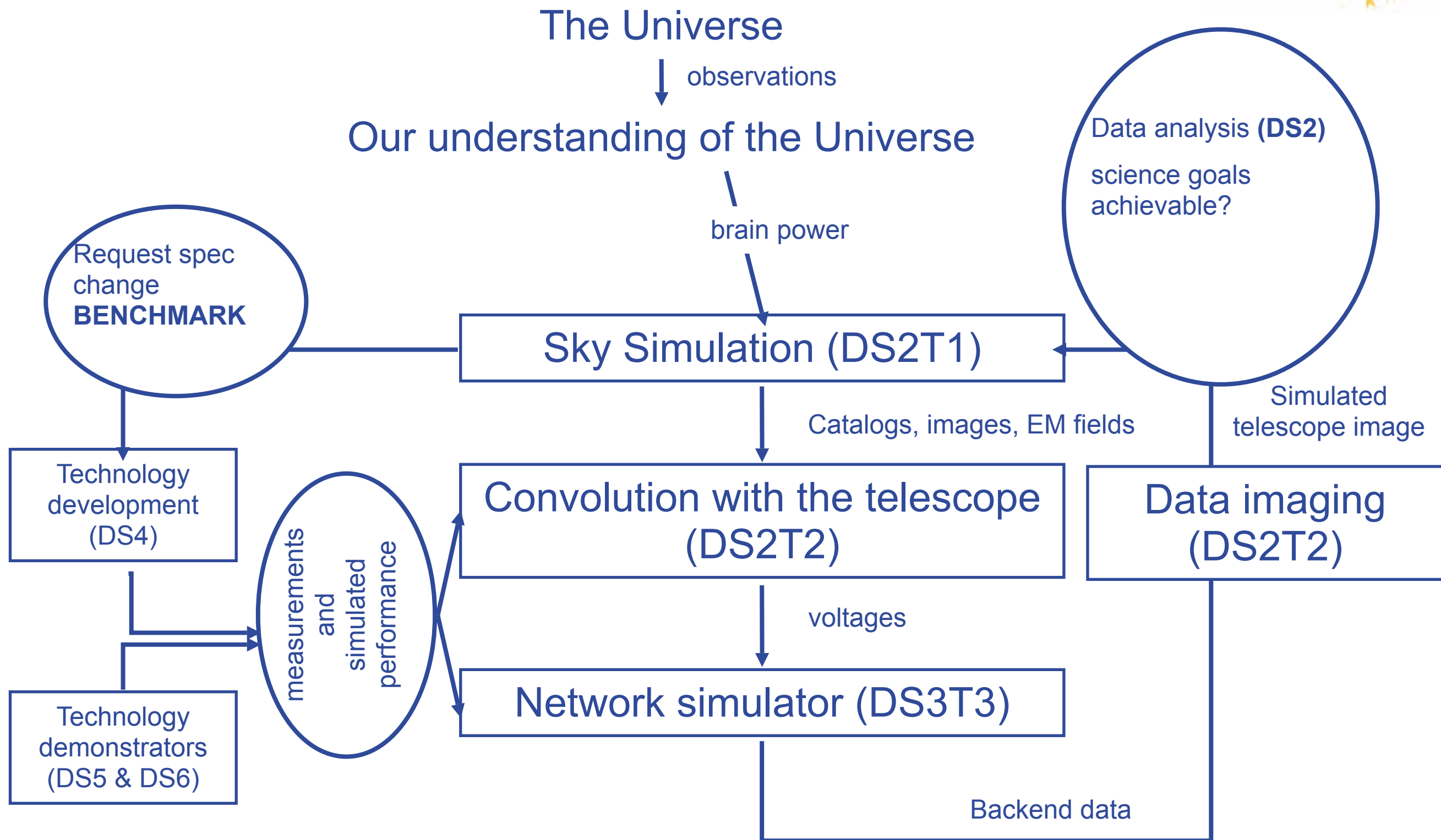


SKADS Organisation





SKADS Science Interactions

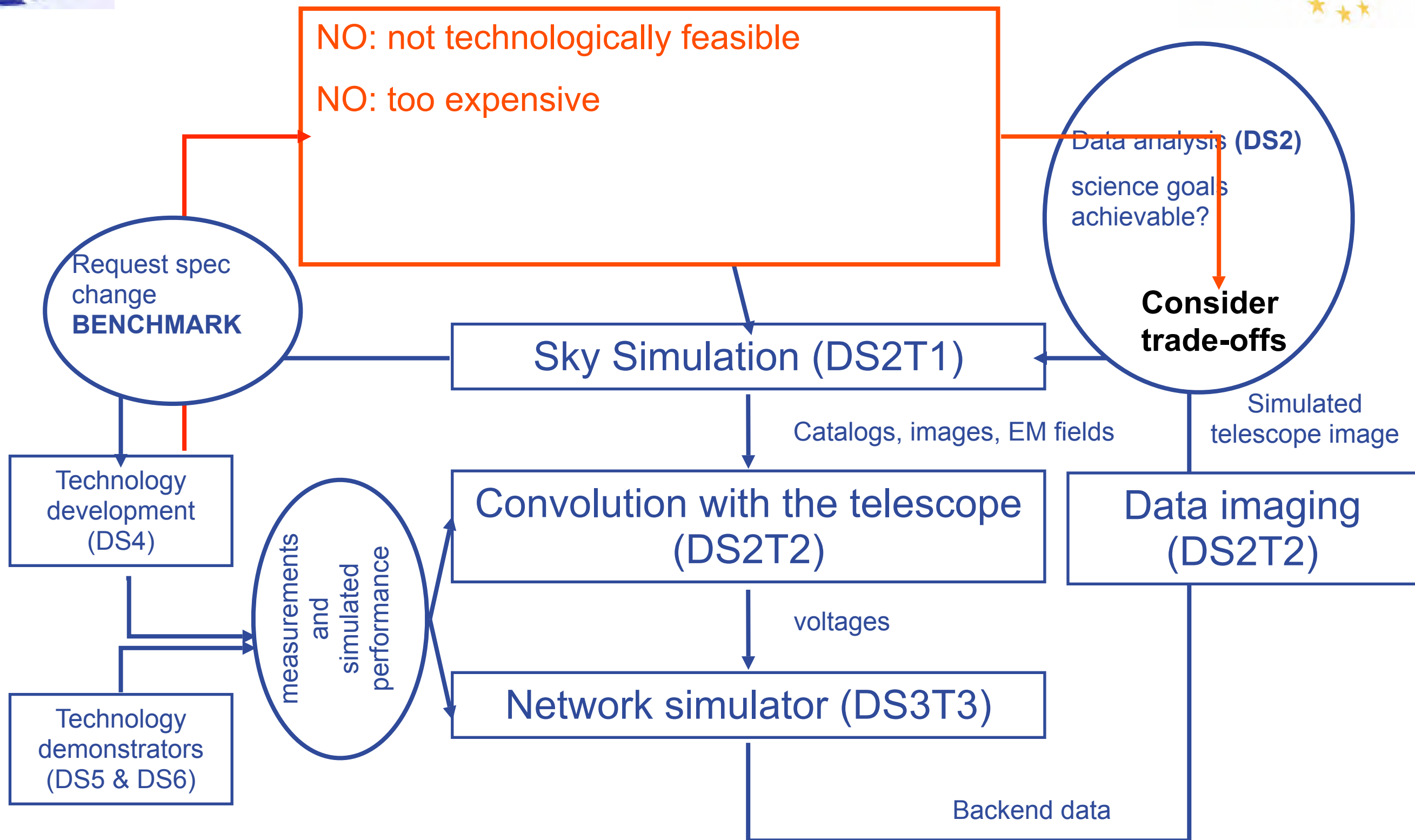




SKADS Science Interactions



NO: not technologically feasible
NO: too expensive





SKA Science Simulations



- Pushchino Radio Astronomy Observatory
- 31 july – 2 August 2007
- <http://www.skads-eu.org/p/pushchino20070730.php>



SKADS Benchmark



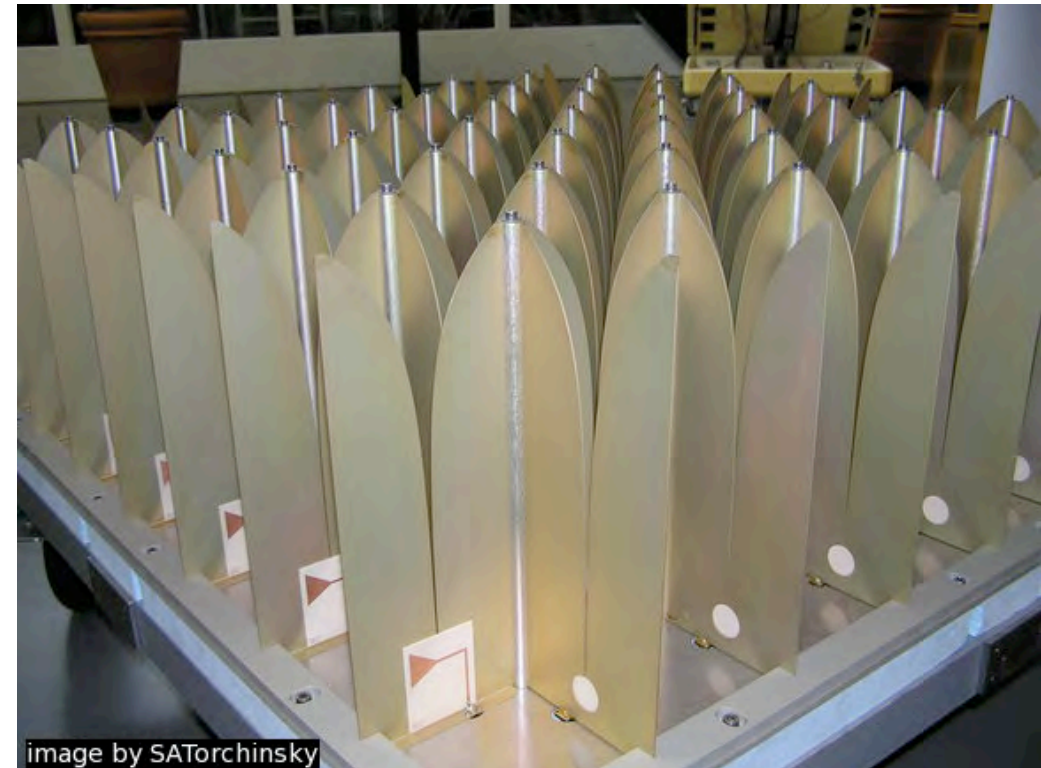
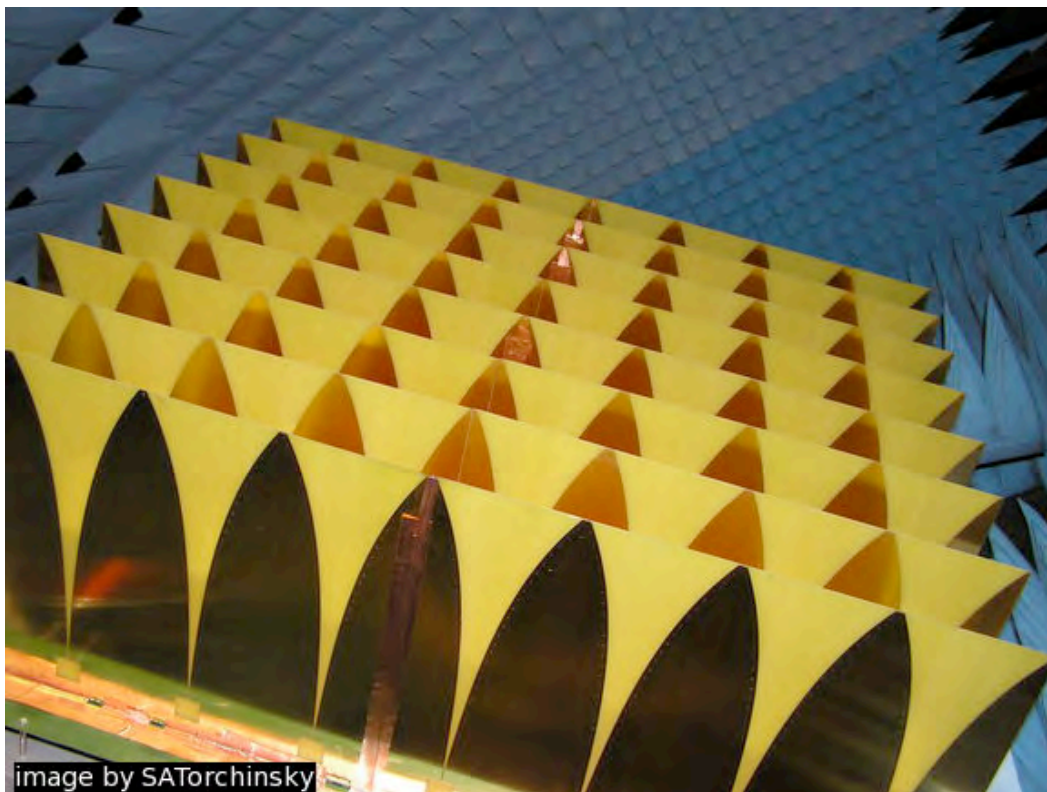
- Detailed implementation of the SKA reference design
- 100MHz – 300MHz sparse phased array (eg. LOFAR)
- 300MHz - ~2GHz dense phased array (eg. EMBRACE)
- >2GHz 6m dishes with FPA
- The benchmark is evolving...
 - <http://www.skads-eu.org>
 - Select “benchmark”
- First version of a costed design:
 - <http://www.skads-eu.org>
 - Select “documents”



Densely packed Aperture-Plane Phased-Array

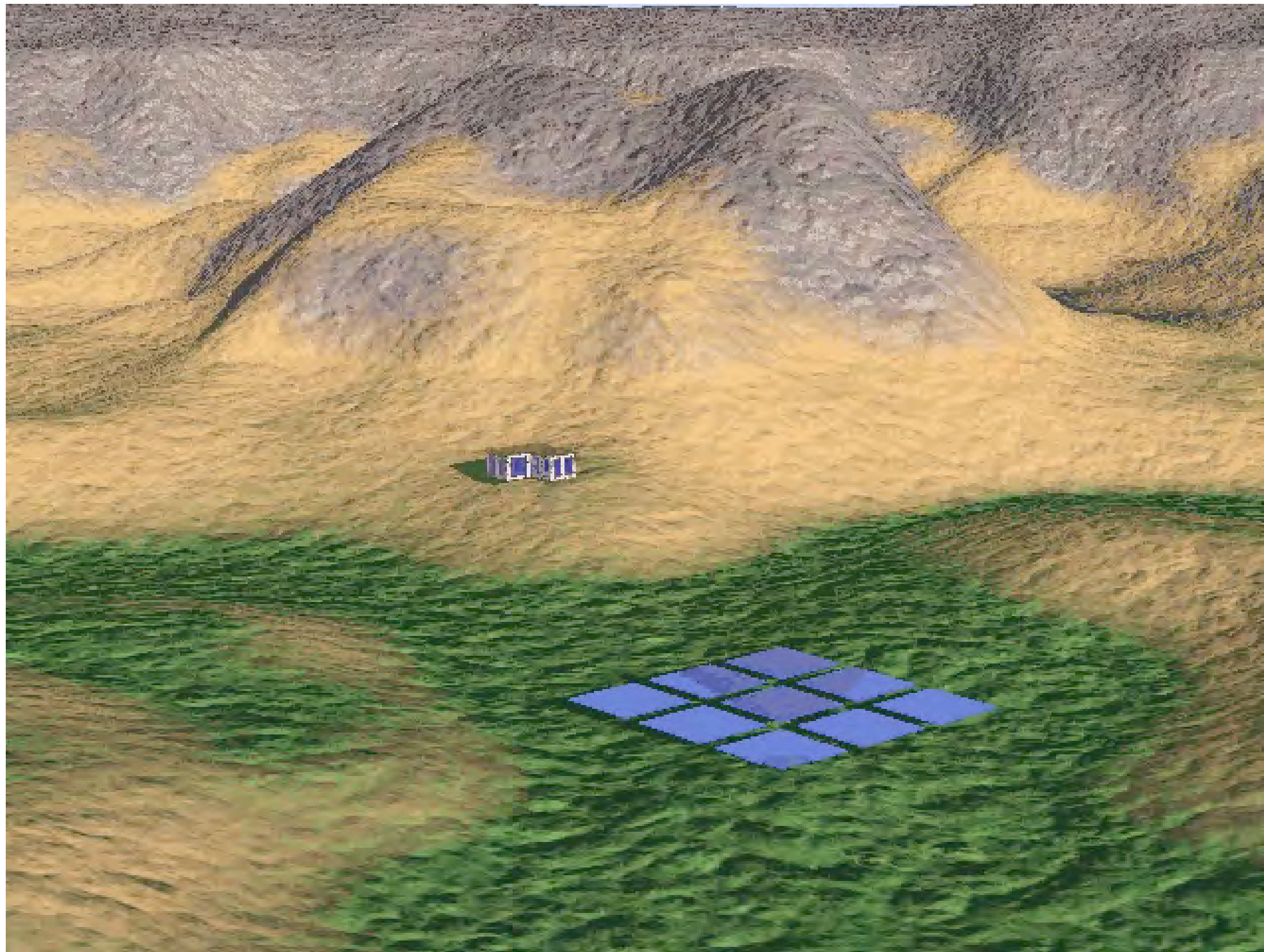


- Vivaldi planar feeds
- 300MHz – 1000MHz





Multibeaming with an Aperture Plane Phased Array





SKADS Benchmark



Parameter	Memos	Benchmark Spec.			Comments
	45/69	EOR AA	Mid-AA	Dishes	
Low Freq. GHz	≤ 0.1	0.1	0.3	1.0	<i>Probably should have some overlap</i>
High Freq GHz	≥ 25	0.3	1.0	25	<i>AA cost goes > square law with top frequency</i>
Bandwidth GHz	25%	0.2	0.7	5	<i>This may be unrealistic for the dishes</i>
Polarisations	2	2	2	2	<i>Default linear</i>
Pol error (after cal): FOV centre/edge dB	-40/-30	-40/-30	-40 /-30	-40/-30	<i>Important for dynamic range.</i>
FOV:					
0.1-0.3 GHz deg^2	200	200			<i>This is really total beam size The FOV naturally scales as $250(1.0/f)^2$ Defined by a 6.1m dish natural beam size.</i>
0.3-1.0 GHz deg^2	50		250		
1.0-3.0 GHz deg^2	1-10			$3(1.4/f)^2$	
3.0-25 GHz deg^2	$0.33(3/f)^2$			$3(1.4/f)^2$	
FOV filling	100%	100%	100%	100%	<i>The full field of view should be filled with beams</i>
No. of steerable FOVs	1-4	4	8	1	<i>AA FOV count limited by comms.</i>
Survey @ 0.7GHz	1.5×10^{19}		1.75×10^{19}		<i>Assumes $10,000\text{m}^2/\text{K}$ sensitivity</i>
Speed: @ 1.5GHz $\text{deg}^2 \text{m}^4 \text{K}^{-2} \text{Hz}^{-1}$	3×10^{17}			8.4×10^{17}	<i>Assumed 700MHz B/W at this freq, 3 deg^2 FOV (FoV x (A/T)² x BW)</i>
System temp Tsys K	50K	>100K	50K	$\leq 30\text{K}$	<i>Assumes dishes use at least 70K cooling</i>
Sensitivity @45° m^2K^{-1} >0.3 GHz	5,000	5,000			<i>The sky noise is v. high for low freq</i>
0.3 – 1.0 GHz	20,000		5-10,000		<i>Red. sensitivity by trading large FOV</i>
1-10 GHz	20,000			10,000	<i>Single pixel feed so can cool for low system temp</i>
>10 GHz	10,000			10,000	
Dynamic range	10^6	10^6	10^6	10^6	<i>Peak b'ness to rms noise level (not ADC range!)</i>



SKADS Benchmark (2)



Parameter	Memos 45/69	Benchmark spec		Comments
		EOR AA	Mid-AA	
Scan range <i>deg</i>	-	$\pm 45^\circ$	$\pm 45^\circ$ $\pm 60^\circ$	$\pm 75^\circ$ Dish scan angle without shadowing
Max Baseline <i>km</i>	>3000	??	3000	3000
Min Baseline <i>m</i>	20	20	20	20
Concentration: %				
< 1km	20%	?50%	20%	20%
< 5km	50%	?100%	50%	50%
< 150 km	75%		75%	75%
				Assumes mid-AA on the longest baselines. What distribution reqd. for EOR array? Pulsar search may require more concentration of the core.
Max no. of image pixels	-	$10^5 \times 10^5$	$10^5 \times 10^5$	$10^5 \times 10^5$
Simultaneous ind. operating bands	2 pairs	ind	ind	ind
Beamformed data <i>Bits</i>	8	8	8	8
				May wish to modify this for different obs. Trading total comms capacity for B/W and resolution
Antenna blind pointing <i>HPBW</i>	0.1	<0.05	<0.05	0.05
				Accuracy for obs.
Antenna Slew rate %/sec	1.5	~0	~0	<1.5
				AA slew 'instantly'
Slew 0.5 HPBW sec	3	~0	~0	<3
				Slew time between adjacent points
Time of day effects	No	??	??	None
	comment			Implies that the LNAs will need to be at least temp stabilised



SKA & SKADS: summary (1)



- 60's – present: Radio astronomy improvements in receiver performance, spectral resolution, data processing
- Arecibo remains largest collecting area for ~50 years
- SKA: proposed as a survey instrument
 - Radio Schmidt proposal -> SKA
 - Finally improve collecting area
 - Global participation
- 2005/06: Key Science and Reference Design for SKA
- SKA demonstrators: LOFAR, MWA, ATA, KAT, MeerKAT, MIRANdA, (EMBRACE)



SKA & SKADS: summary (2)



- Key Science
 - Large Scale Structure
 - Epoch of Reionisation
 - Cosmic Magnetism
 - Tests of General Relativity in Extreme Fields
 - Cradle of Life
 - The Unknown
- SKA Reference Design
 - Central ~3km aperture-plane phased-array (EMBRACE)
 - Annulus of dishes out to 5km
 - ~200 stations of dishes (and dipoles for low frequency)



SKA & SKADS: summary (3)



- SKADS <http://www.skads-eu.org>
 - Mainly European
 - Concentrating on aperture-plane phased-array
 - EMBRACE demonstrator
 - Science simulations
 - SKADS Benchmark:
 - Detailed implementation of the SKA reference design
 - Costing analysis