The Square Kilometre Array

Michael Kramer
Max-Planck Institut für Radioastronomie

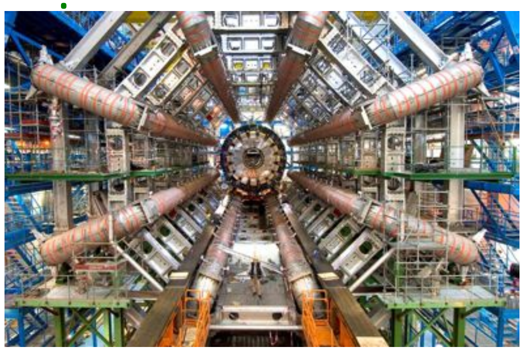
Time for Big Machines

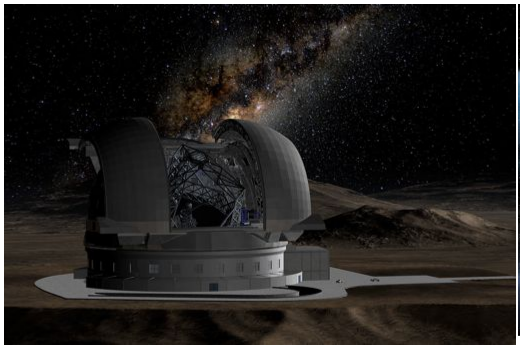
We live in exciting times:

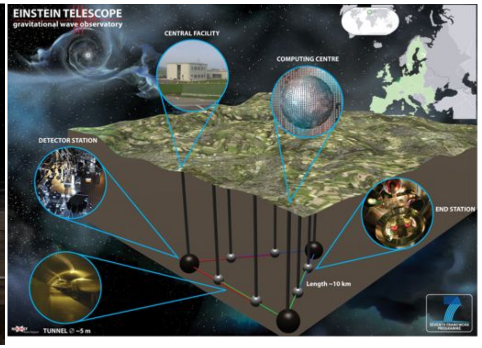
- we are on the verge of confirming some of the most revolutionary theories
- we find clues as to whether these theories are complete or not
- we may find a way to describe large and small scales with one theory
- we are about to trace the complete history of the universe
- we are about to study extra-solar worlds and Earth-like planets
- we are about to open a truly new window to the Universe

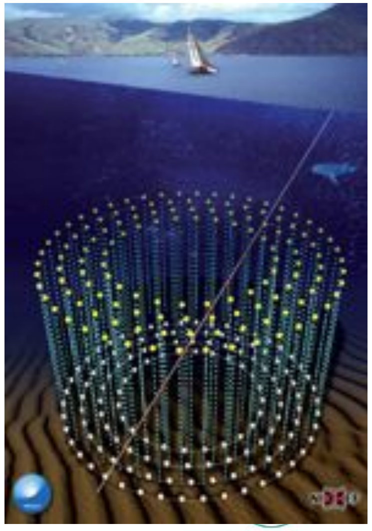
But.... It takes increasing efforts to make such fundamental and important discoveries – it needs (typically) BIG machines

!









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But…. It takes increasing efforts to make such fundamental and important discoveries – it needs (typically) BIG machines

These machines need to be powered – for a long time, hopefully!

➔ Running costs as well as carbon footprint must be addressed!

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Outline

A (radio) astronomical example…

- Introduction
- The Square Kilometre Array
- Project Plan and Status
- The Challenges
- Conclusions

Introduction

Radio Astronomy

Arguably, most of the fundamental astrophysical discoveries of the last century were made by radio astronomers, e.g.

Pulsars

Gravitational waves

Extra-solar planets

Cosmic Microwave Background

Quasars and radio galaxies

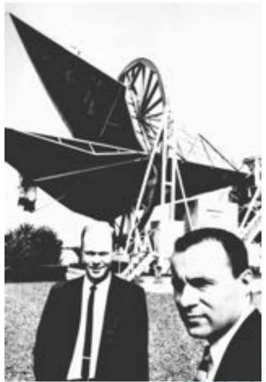
Gravitational lenses

Jets and super-luminal motions

Dark matter

Interstellar molecules

Masers and megamasers



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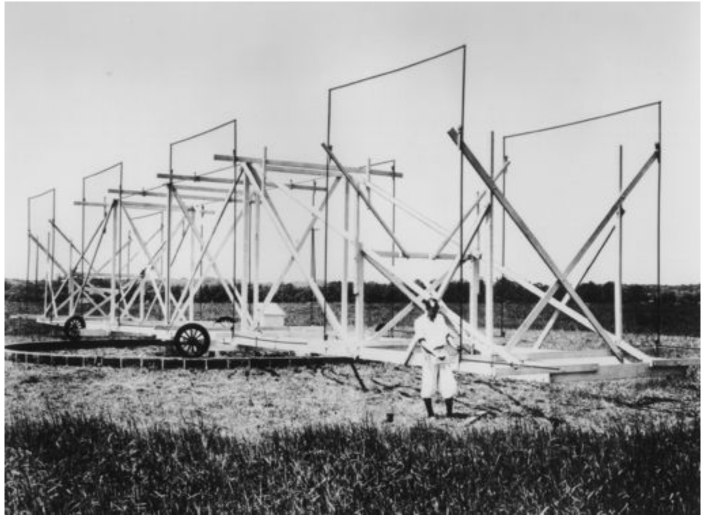
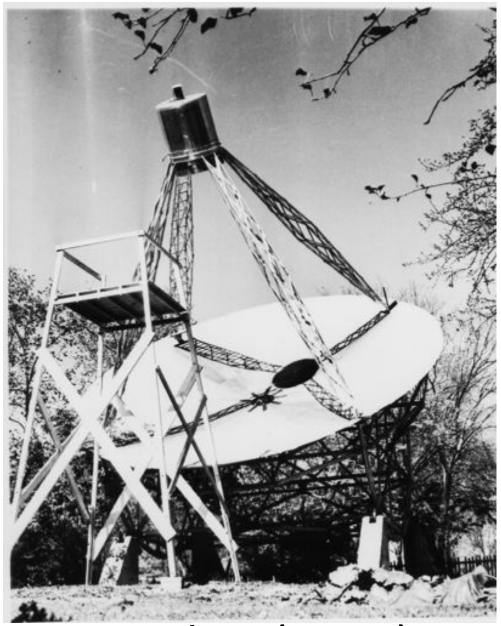
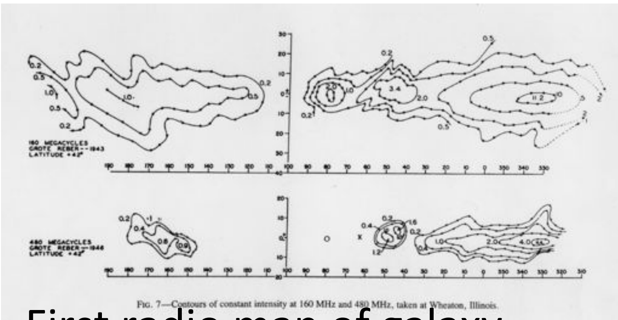
Still a rather young branch of astronomy:



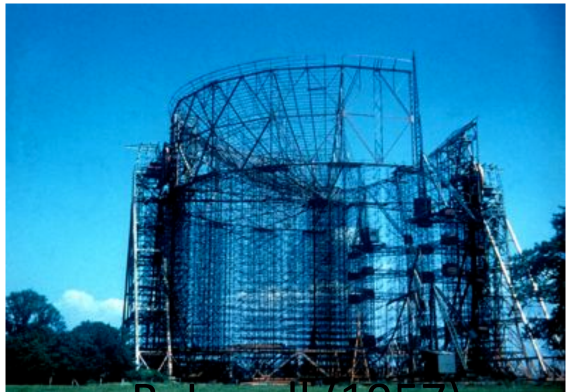
K. Jansky (1933)



G. Reber (1938)



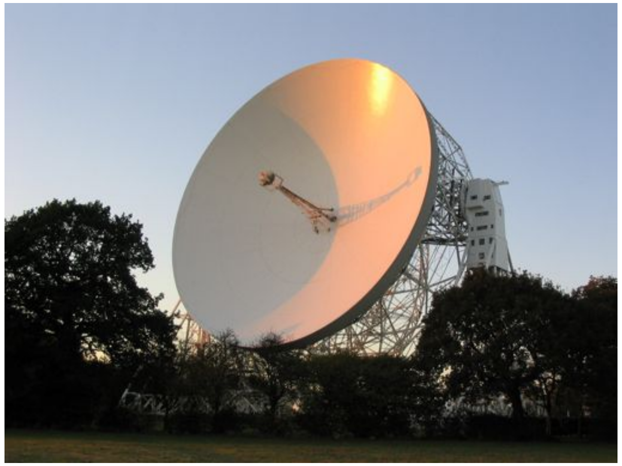
First radio map of galaxy



B. Lovell (1957)

Current state-of-art

Lovell 76-m



GBT 100-m

Arecibo 300-m

Effelsberg 100-m

VLA 27x25-m

Parkes 64-m

Plus new major ones very soon: ALMA, LOFAR etc…

Radio Astronomy Sensitivity

Sensitivity:

$$S_{\min} = \frac{2kT_{sys}}{A_{eff}\sqrt{\tau \times \nu}} = \frac{T_{sys}}{G}\frac{1}{\sqrt{\tau \times \nu}}$$

Gain:

$$G = \frac{A_{eff}}{2k}$$

Most Receivers are already at the quantum limit = T_{sys} already minimal

Need to find other ways to improve sensitivity:

- Increase gain = collecting area (A_{eff}) = bigger telescopes!
- Increase bandwidth (ν) despite increasing man-made RFI!
- Enable longer integration time (τ) = cover more sky per minute!

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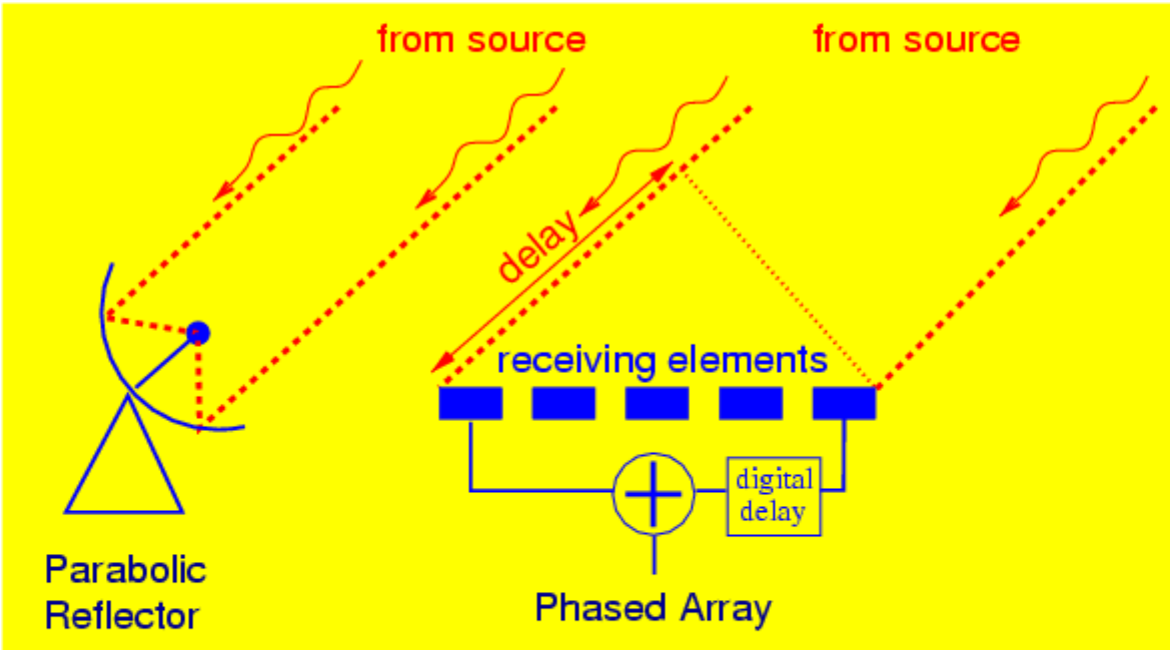
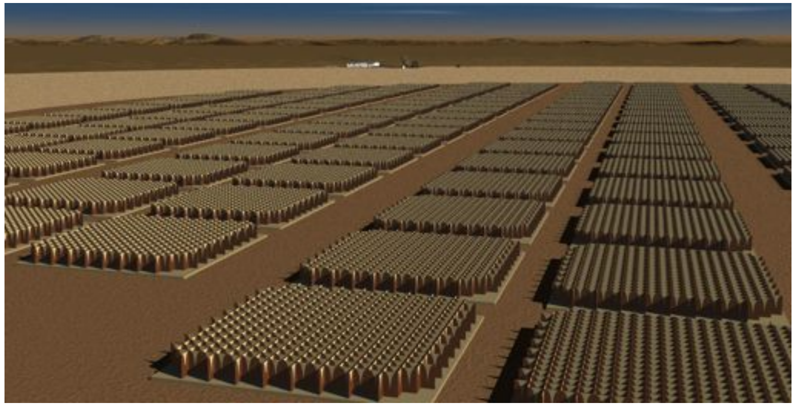
A Revolution in Radio Astronomy

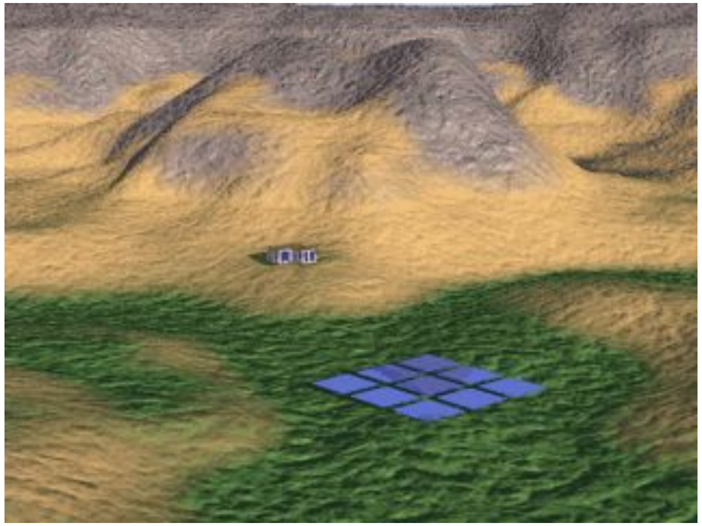
- Go digital! Ability to sample, digitze & process wide bandwidths
- Use of commodity computing power (incl. GPUs) and FPGAs
- Ways of obtaining "cheap" collecting area
- Replacing hardware (i.e. metal) with electronic and software
- Build "radio cameras" to increase "field-of-view" on sky and even allow to look in (sometimes) vastly different directions:



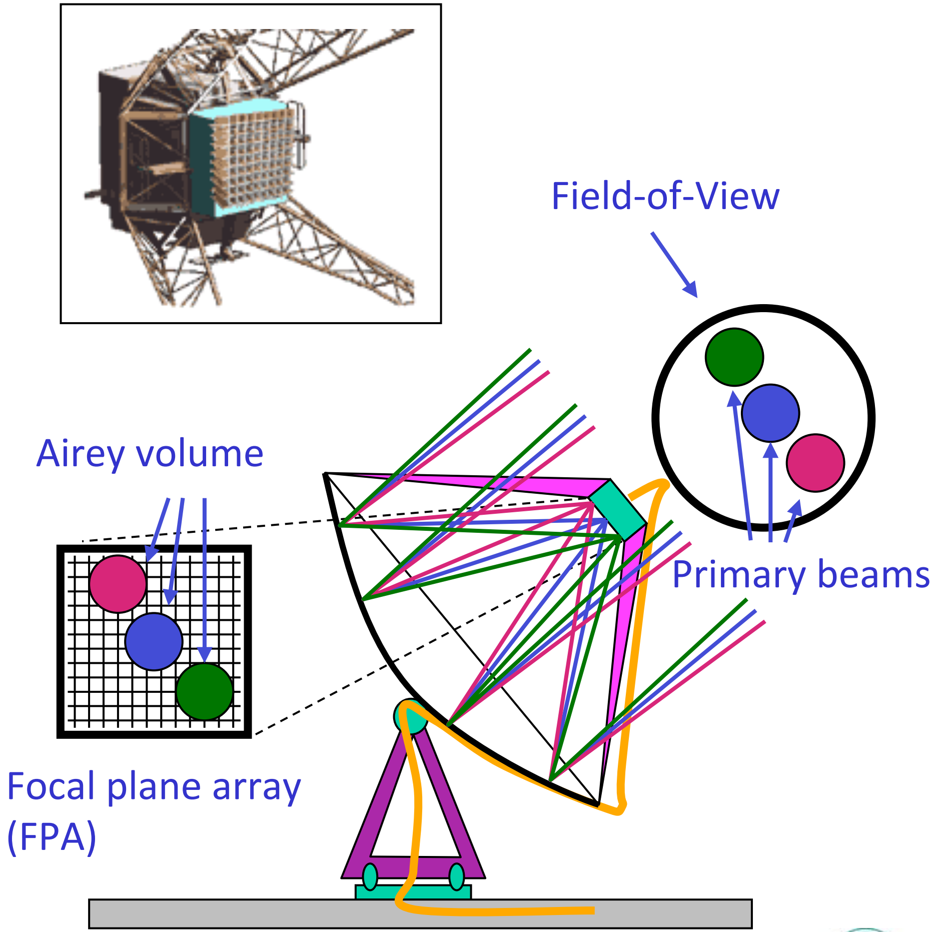
Aperture Arrays & Focal Plane Arrays

= phased array on ground



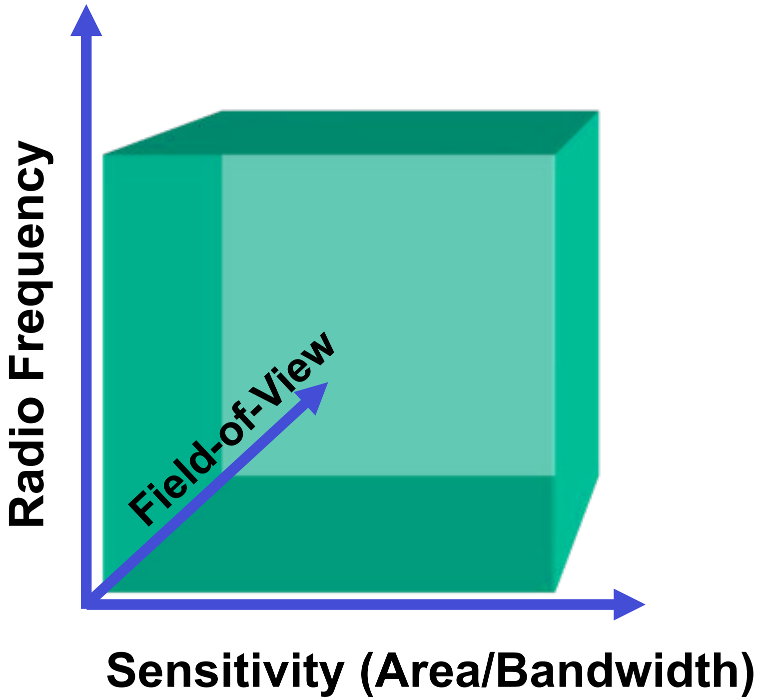


= phased array in focus of dish



NEW: HUGE Field-of-View and multiple beams within FoV!

New technology: huge increase in phase space



- Sampling large bandwidths (20-50%)
- Providing huge FoVs (>30 sq-deg) hence huge survey speed
- Large frequency range, e.g. opening low-frequency sky (LOFAR etc.)
- Brute-force increases in collecting area (SKA, LOFAR)
- Digital signal processing
- Huge computing power…

➔ New science and new discoveries!

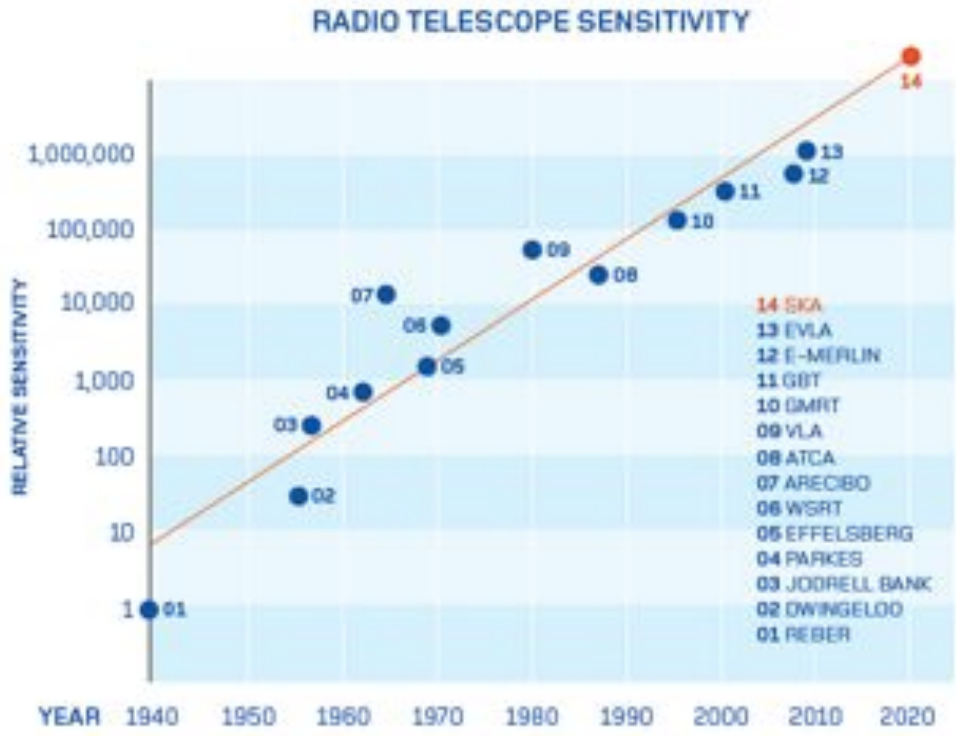
The Square Kilometre Array

The Telescope

In a nutshell: The SKA is…

…a large radio telescope for transformational science

- up to 1 million m^2 collecting area distributed over a distance of 3000+ km
- operating as an interferometer at frequencies from 70 MHz to >10 GHz
- connected to a signal processor and high performance computing system by an optical fibre network



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…providing

- 100 x Effelsberg, and 10 x Arecibo, and
- at least 10,000 x survey speed of current telescopes

HST

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…67 institutes in 20 countries are participating

- on ESFRI List as only global project (selected for construction)
- with E-ELT selected for highest priority on EU ASTRONET roadmap
- US Decadal Review ASTRO2010: "long-term future of radio astronomy"
- Canadian Long-Range Plan: SKA next priority behind TMT (10%!)
- African Union Heads of State acknowledge importance
- Australia and South Africa invest about €200M each

The Telescope

The Telescope

Construction will proceed in two phases: SKA_1 → SKA_2

- SKA_1 will be a subset (~10%) of SKA_2

- Major science observations already possible with SKA_1 in 2020:

  - Neutral hydrogen in the universe from Epoch of Re-ionisation to now
  - Fundamental forces: pulsars, gravity and gravitational waves

- Phased construction allows maximum use of advances in technology:

Phase I: SKA_1 can be built now with proven and secure technology (baseline)
Phase II: SKA_2 can make use of new, future matured technology (AIP)

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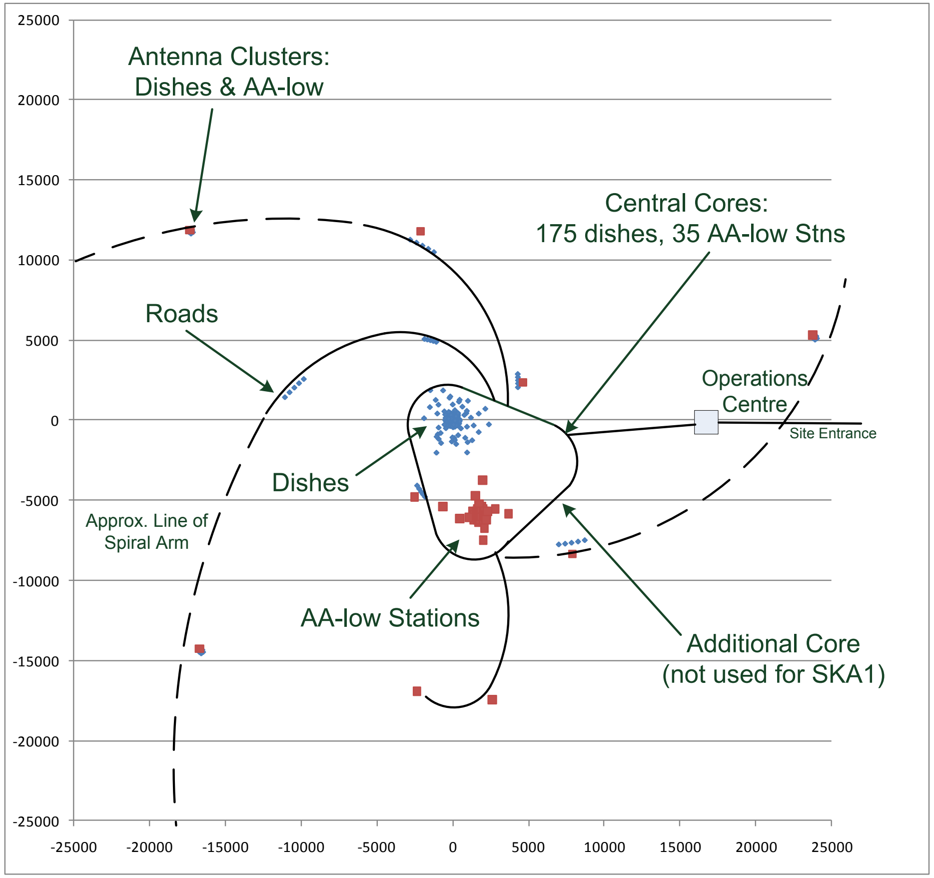
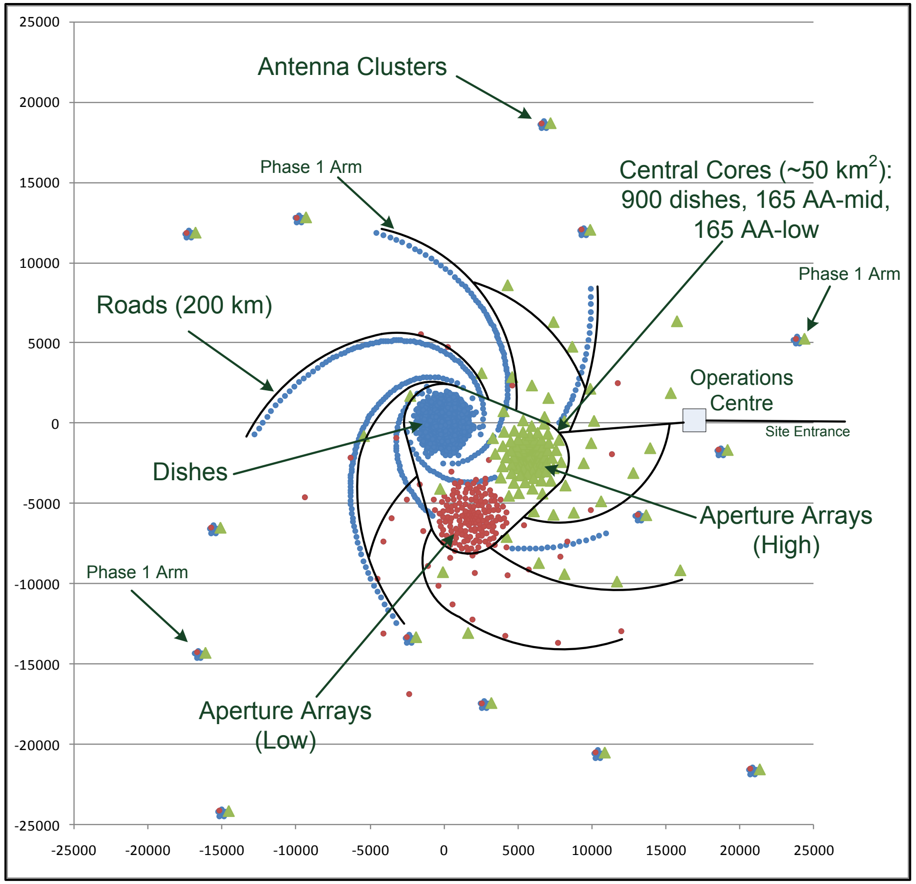
From Phase I to Phase II

Central SKA1 Site



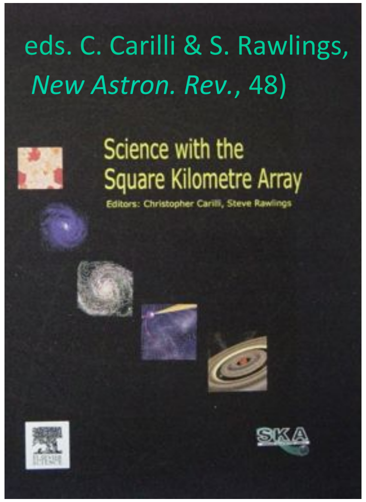
Central SKA2 Site



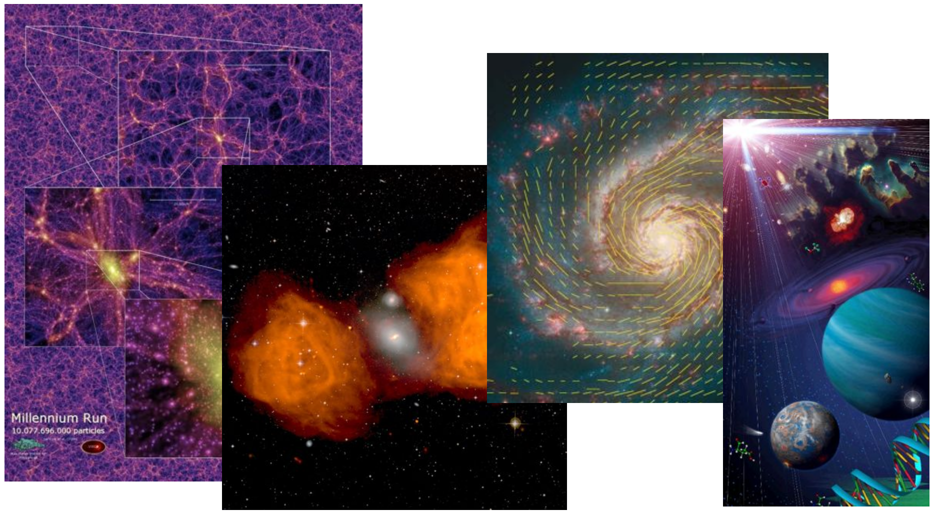
SKA Key Science

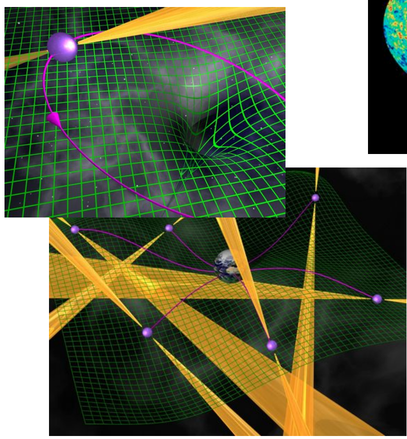
Five Key Science Projects incl.:

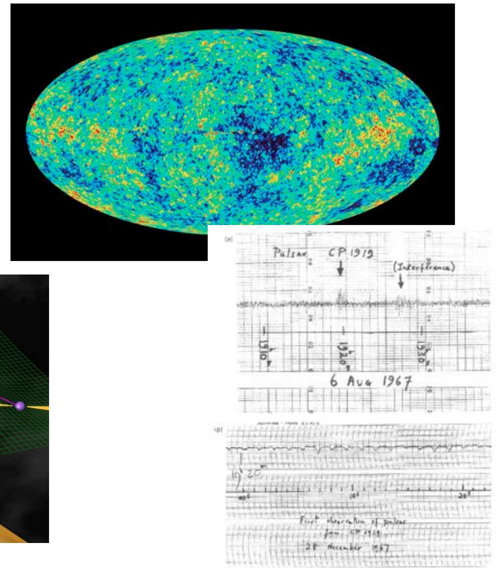
- Dark matter, cosmology and Dark energy
- Dark ages: First stars and black holes
- Cosmic magnetism
- Cradle of life
- Strong-field tests of gravity using pulsars & black holes



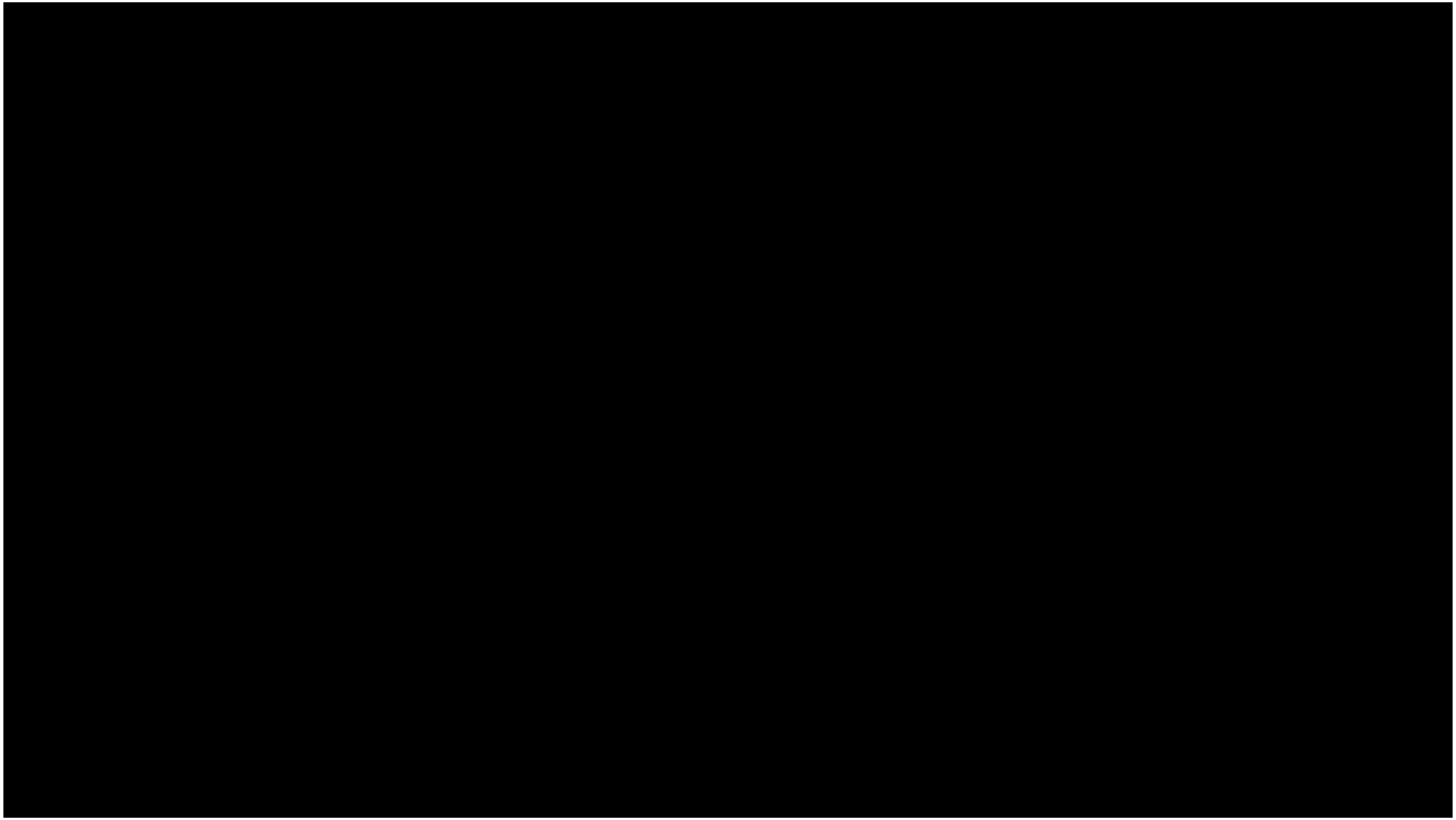
+ Exploration of Unknown







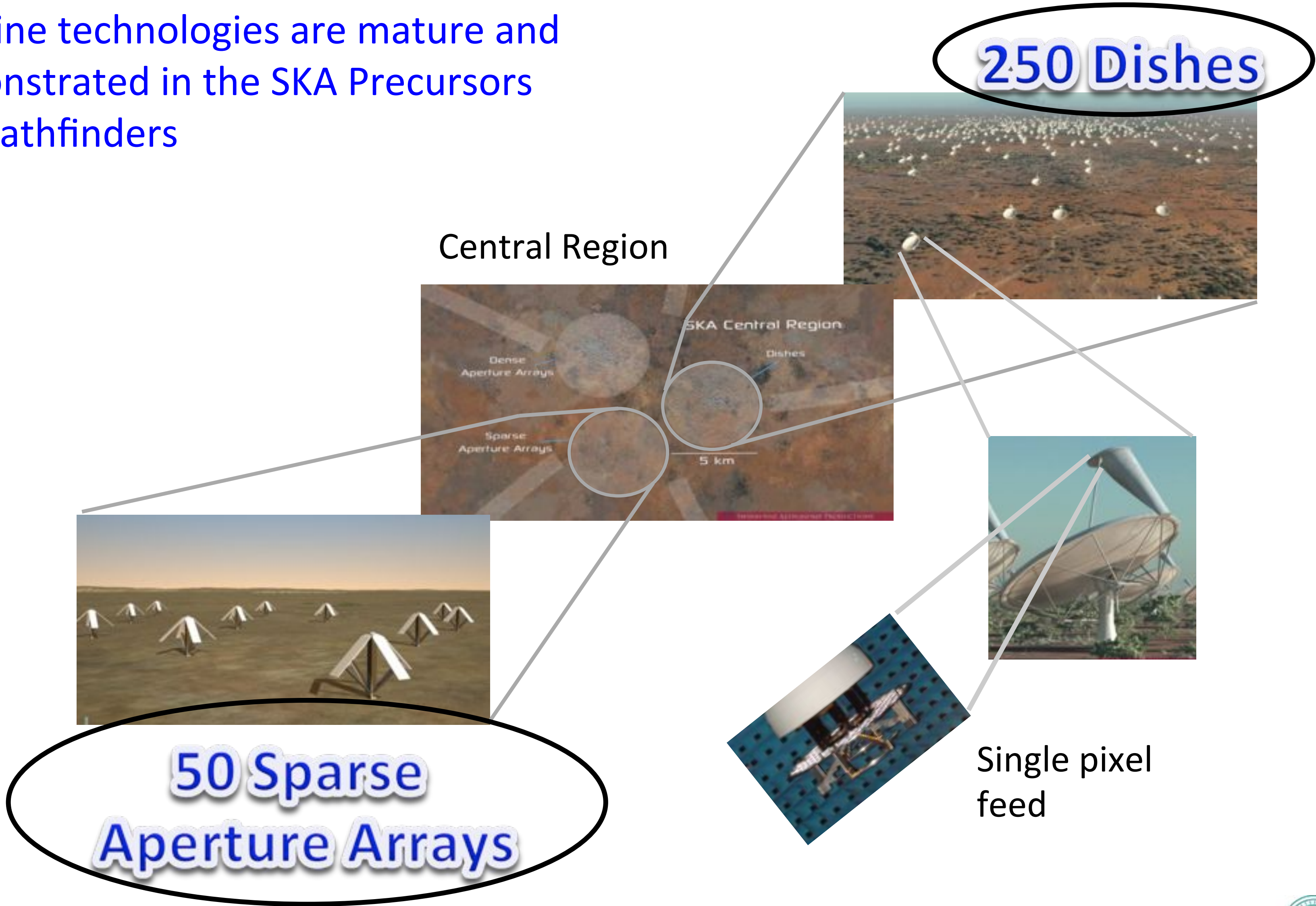
Science Drivers



Project Plan & Status

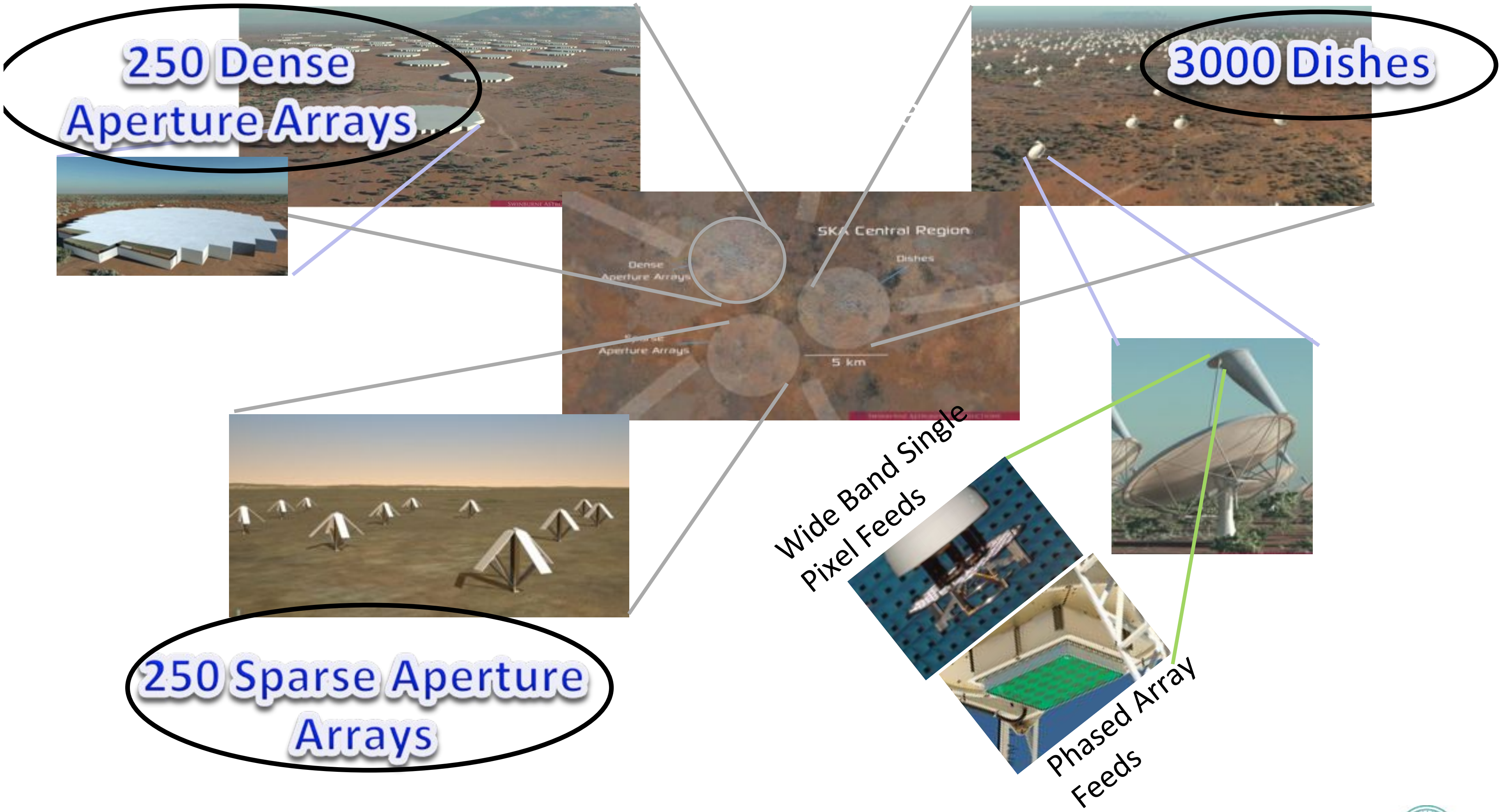
SKA$_1$ baseline design

Baseline technologies are mature and demonstrated in the SKA Precursors and Pathfinders



SKA$_2$ including AIP technologies

The Advanced Instrument Programme is designed to build maturity and retire risk



AIP elements tested and developed in SKA Pathfinders

SKA System Design (2007-2012)

Contributing programs

EC FP6 SKA Design Study (SKADS)

EC FP7 Preparatory Phase (PrepSKA)

US Technology Development Program

“Pathfinder” telescopes like LOFAR, ATA

“Precursor” telescopes on the candidate sites (ASKAP, MeerKAT)

LOFAR (Europe)

ATA (USA)

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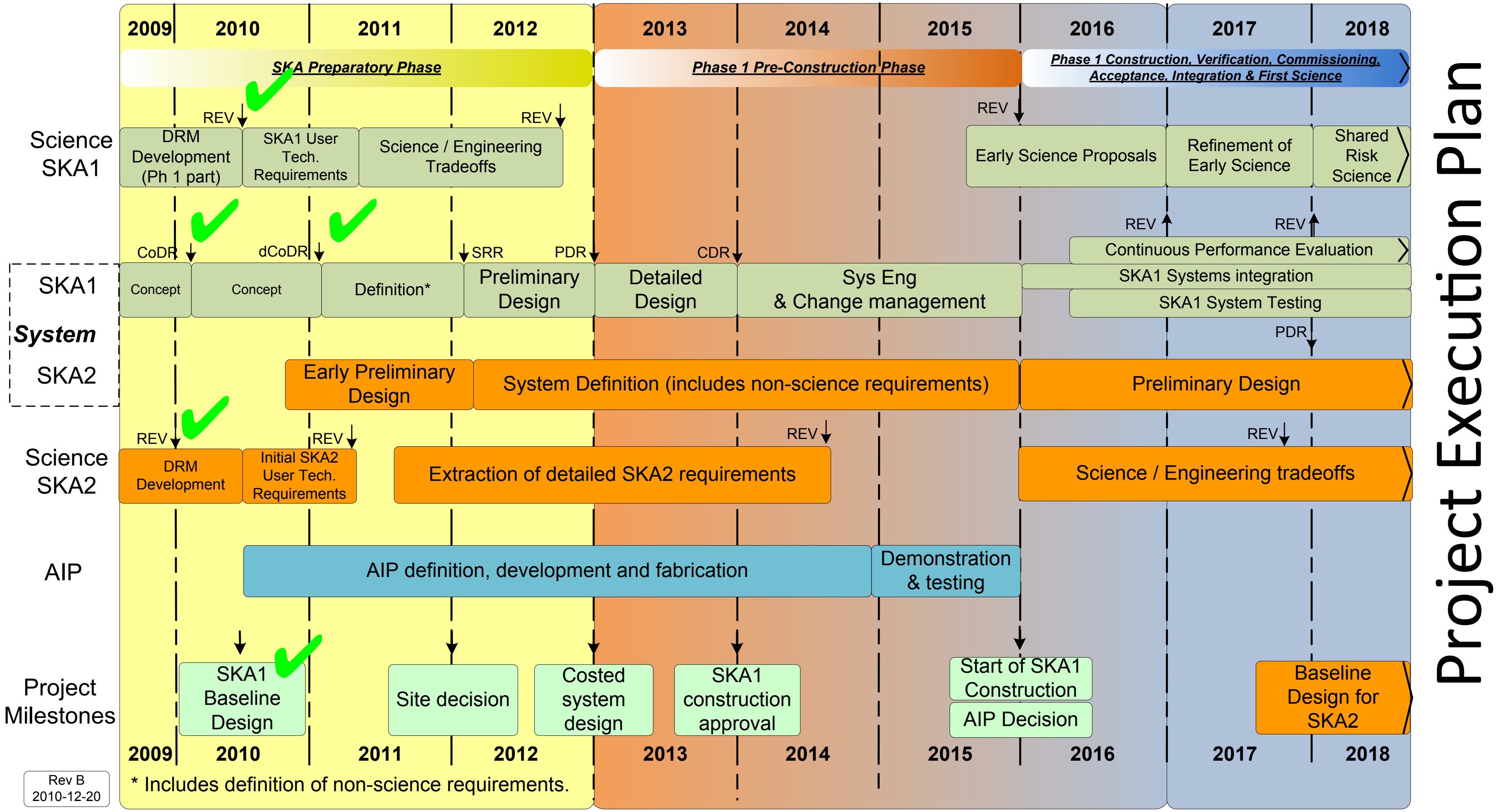
ASKAP (Australia)

KAT-7/MeerKAT (SA)

Timeline

Preparatory Phase → Preconstruction Phase → SKA_1 Construction



Current task in 2011 and 2012 is to convert this SKA-relevant design and development into PDR-ready SKA-specific designs and costs

Total resources proposed (4 years): 90.9 M€

External independent review

External Review of the Project Execution Plan

At the ASG meetings in June 2010, the group commissioned the preparation of a 'Project Execution Plan' (PEP) to describe the required technical and organisational programme for the SKA in the pre-construction period. Following initial discussion of the resulting PEP in October 2010, it was agreed that an external expert review would be organised to consider the PEP and report back to the ASG at the March 2011 meetings.

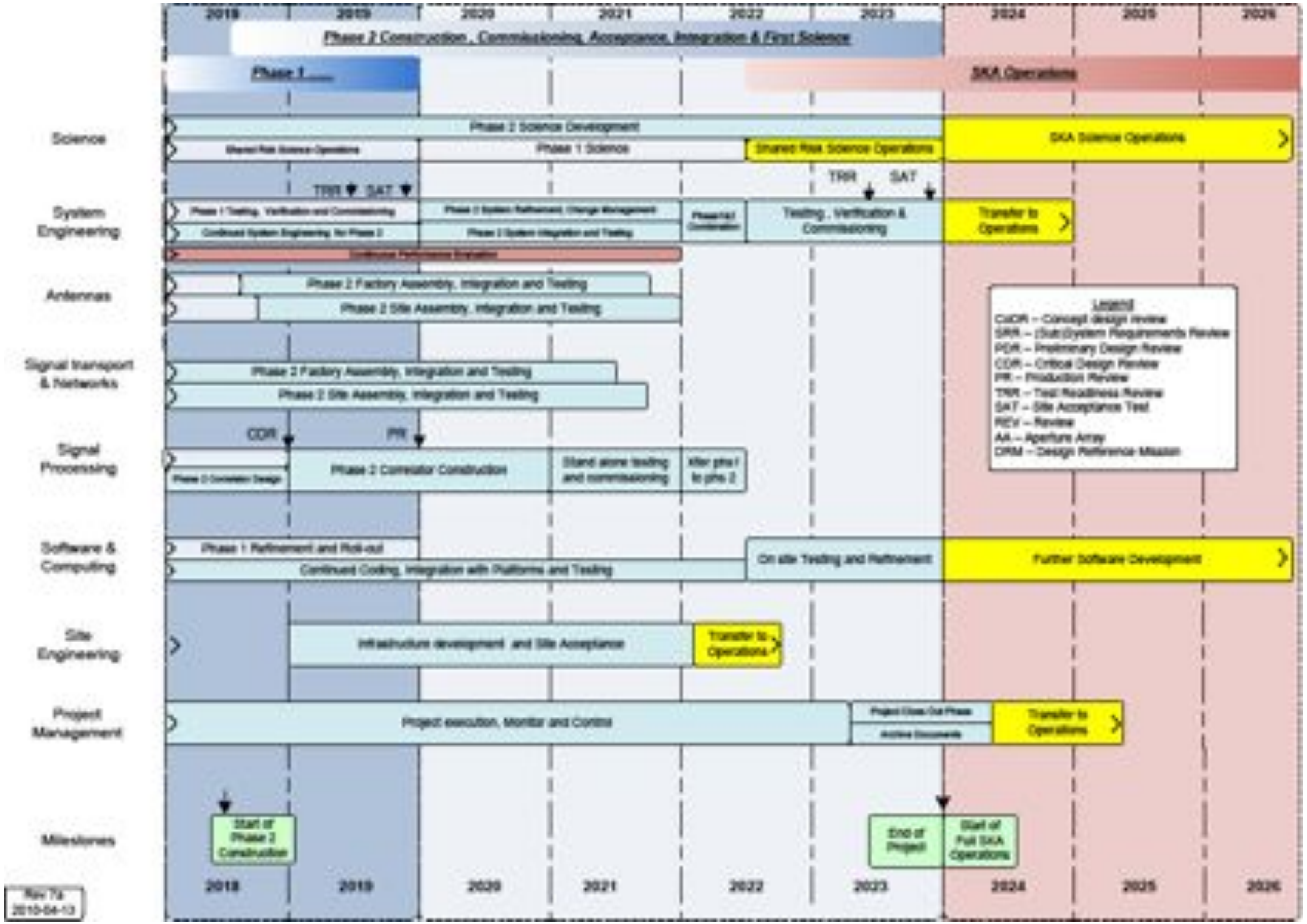
Following this instruction, a Panel was organised to undertake the review. The membership was:

- Gary H. Sanders – Caltech/Thirty Metre Telescope – Panel Chair
- Ian Bird – CERN
- Antonella Calvia – European Investment Bank
- James H. Crocker – Lockheed Martin Space Systems
- Adrian Russell - ESO

The Panel met on 8-9th March 2011 in Brussels (financial support from the EC is acknowledged for this process). Simon Berry and Elena Righi-Steele were in attendance.

Further Timeline

SKA$_1$ Construction→ SKA$_2$ construction



Top level schedule for the SKA

Technical

2008-12	telescope system design and cost
2013-15	detailed design in the pre-construction phase
2016-19	Phase 1 construction
2016	Advanced Instrumentation Program decision
2018-23	Phase 2 construction
2020→	full science operations with Phase 1
2024→	full science operations with Phase 2

Programmatic

2011	approve funding for pre-construction phase
	establish SKA organisation as a legal entity
	select location for SKA Project Office
2012	site selection
2014	approve construction funding for Phase 1 (350 M€, 2007)
2018	approve construction funding for Phase 2 (1.2 B€, 2007)

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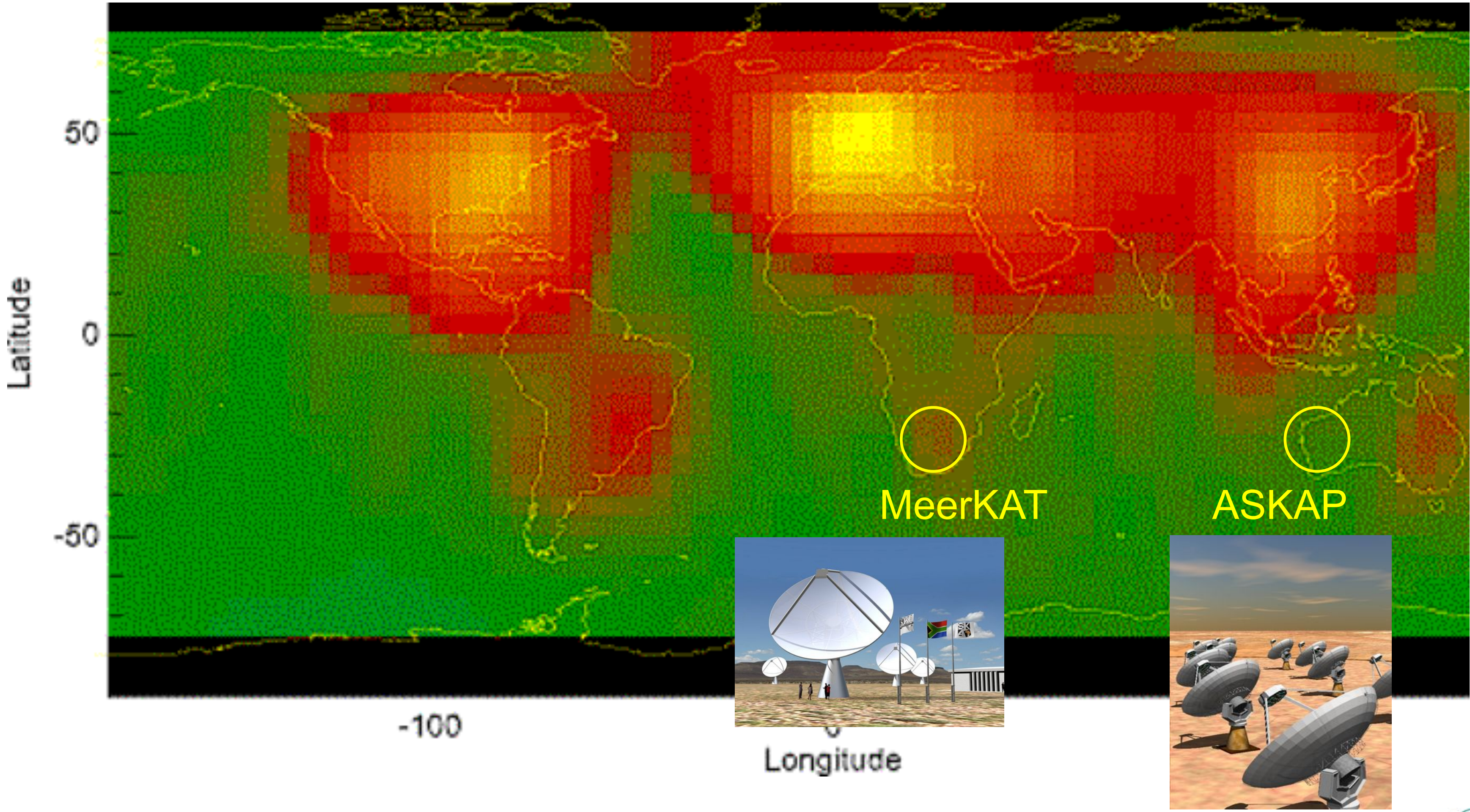
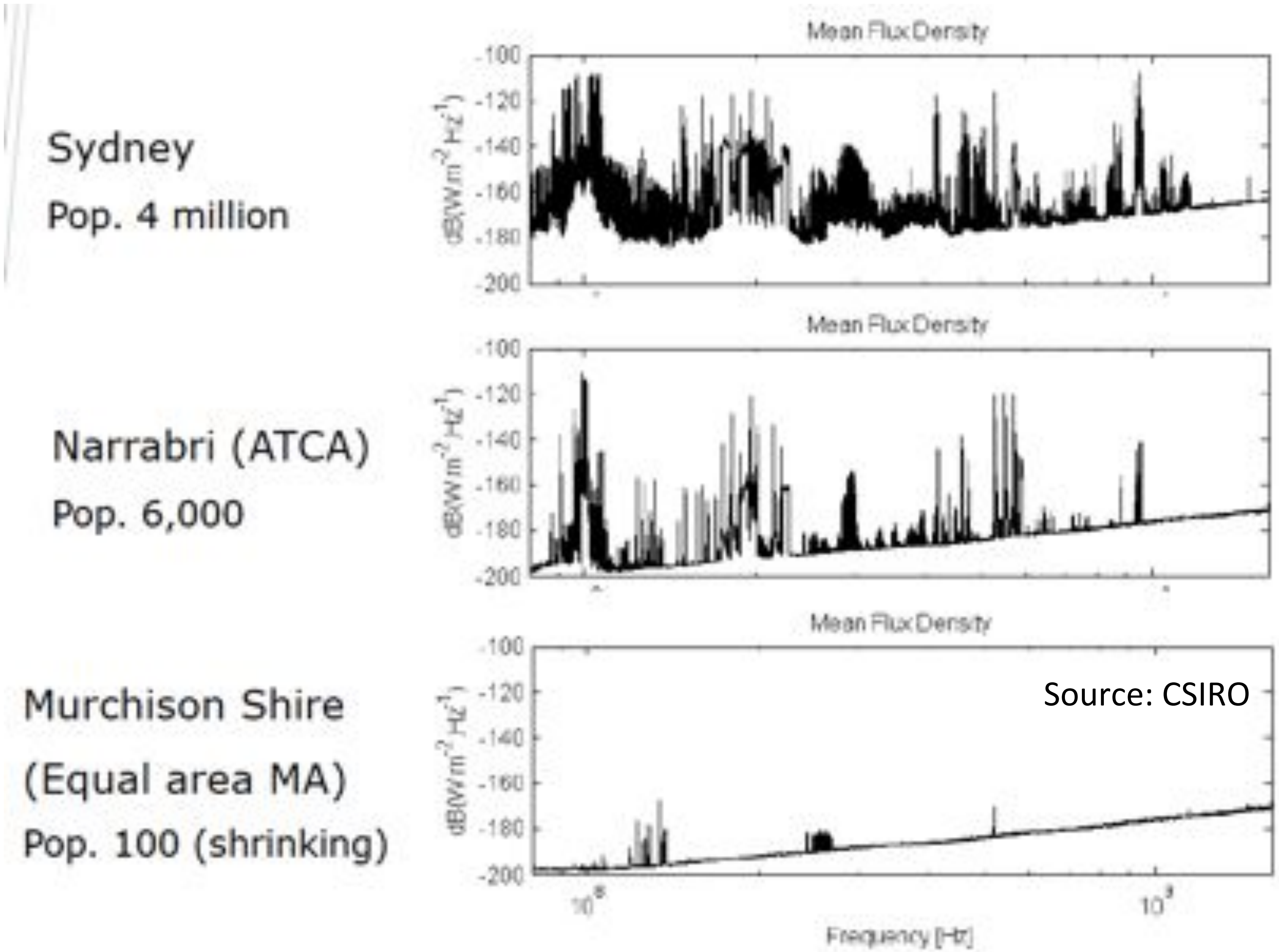
Where to go?

Man-made radio emission (Radio Frequency Inteference, RFI):



Where to go?



We need to be at site far away from population centres – away from grid?

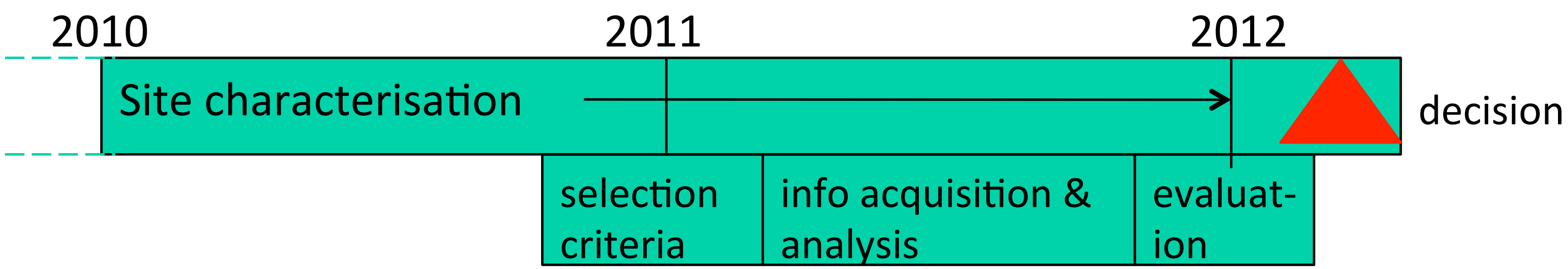
Site selection

Physical requirements

- Extremely radio quiet environment
- At least 3000 km in extent
- Low ionospheric turbulence
- Low tropospheric turbulence

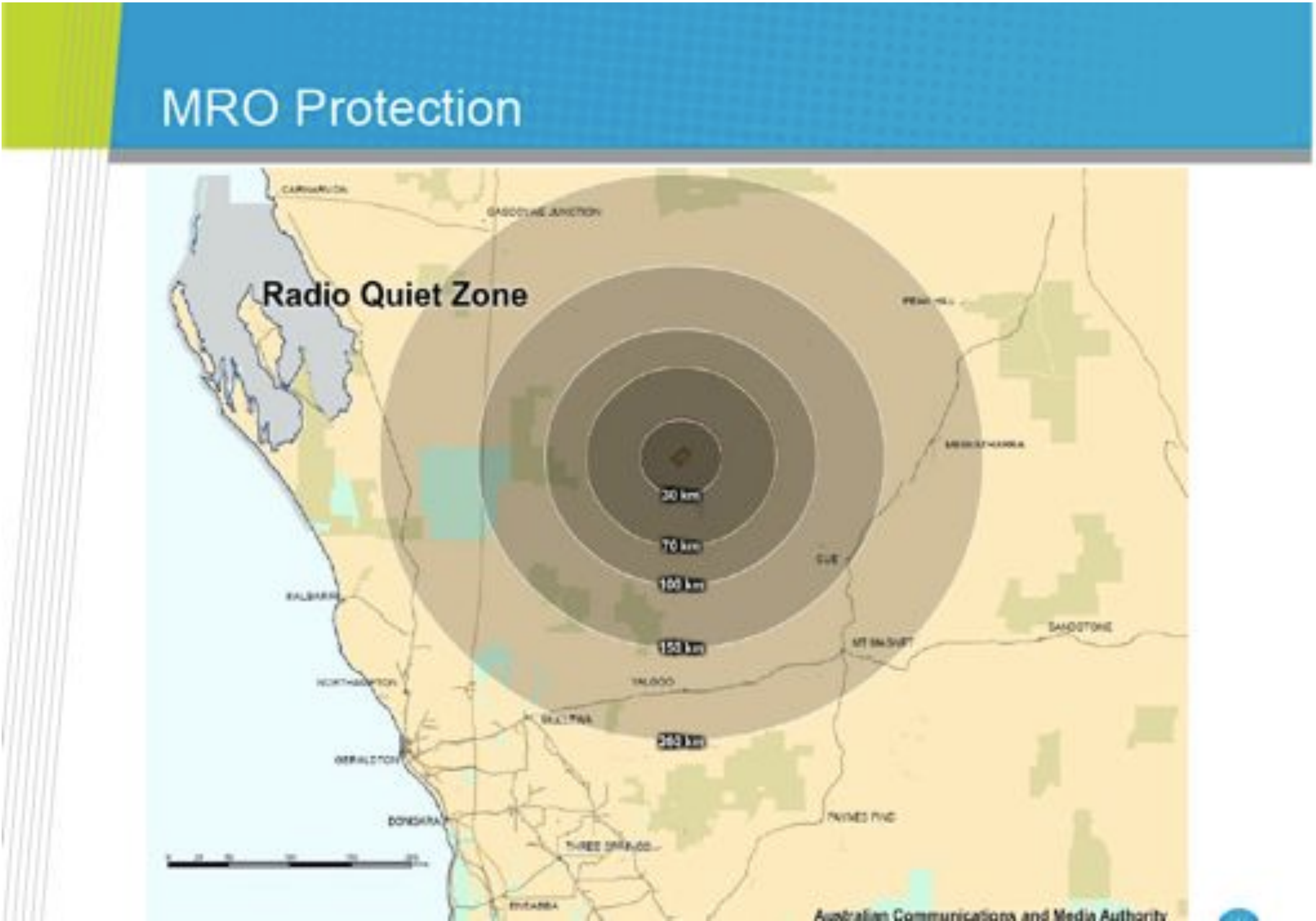
Two candidates short-listed in 2006: Western Australia and Southern Africa

Site selection process



Western Australia & New Zealand

Legal regulations in place to protect site



South Africa + 7 countries

South Africa + 7 countries

The Challenges

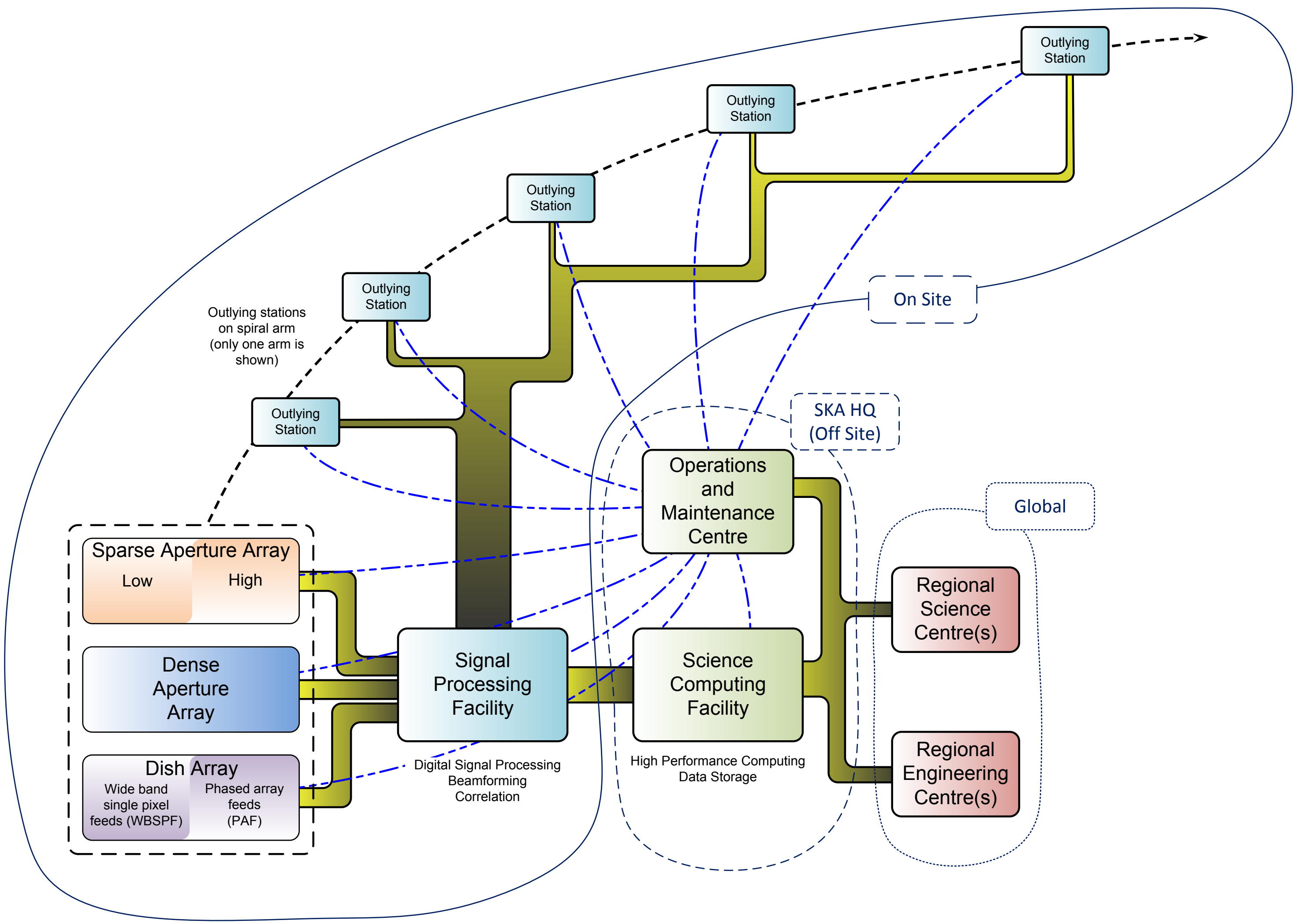
Challenges

- The radio astronomical techniques are under control
- The most important challenges are instead from:

  - Computing
  - Power supply

related

System Block Diagram



Signal transport networks

European Very Long Baseline Interferom... Network (1 Gb...

EC ... ReS

Every day more than all information collected by humankind so far

SKA data rates

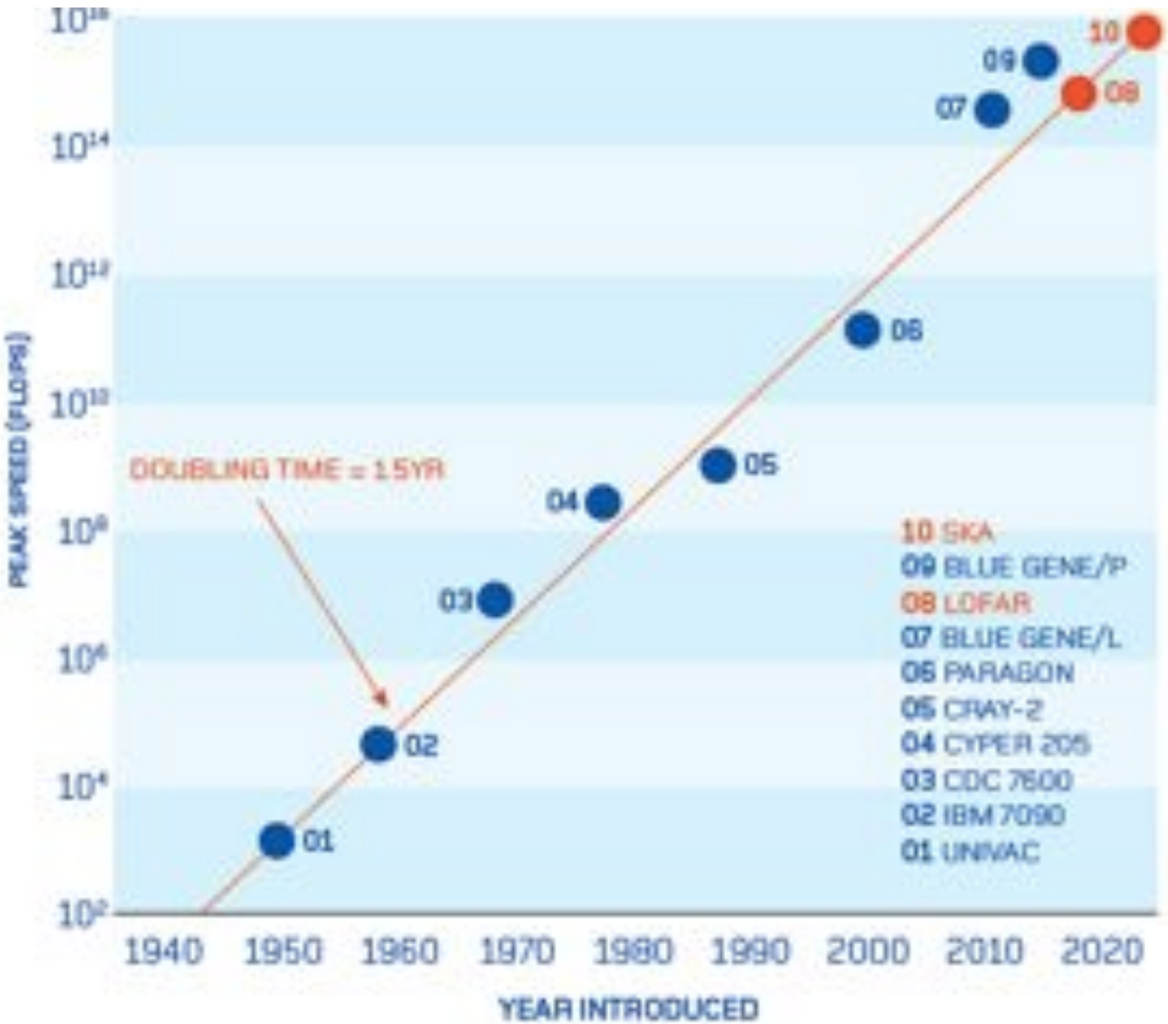
80 Gbit/s/beam/dish (<200km)

40 Gbit/s/station (20 dishes) (>200km)

~100 Tbits/sec!

About 1 Exabyte per day!! – We need Exa-Scale HPC!

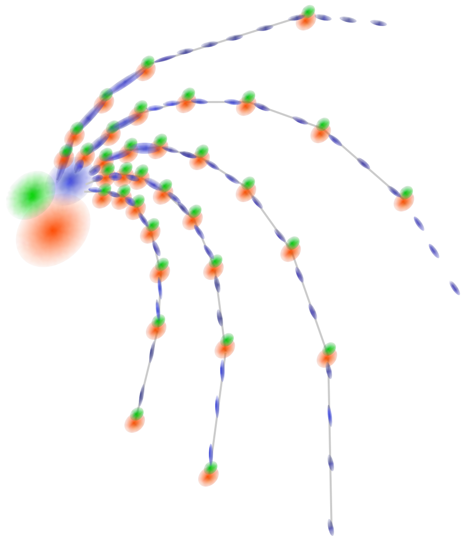
We need an ExaFlop Computer on-site!



- In line with ESFRI PRACE goals
- But, we need to make HPC more energy efficient to achieve goal!
- In Germany, collaboration with FZ Juelich to develop solutions for SKA

Energy supply

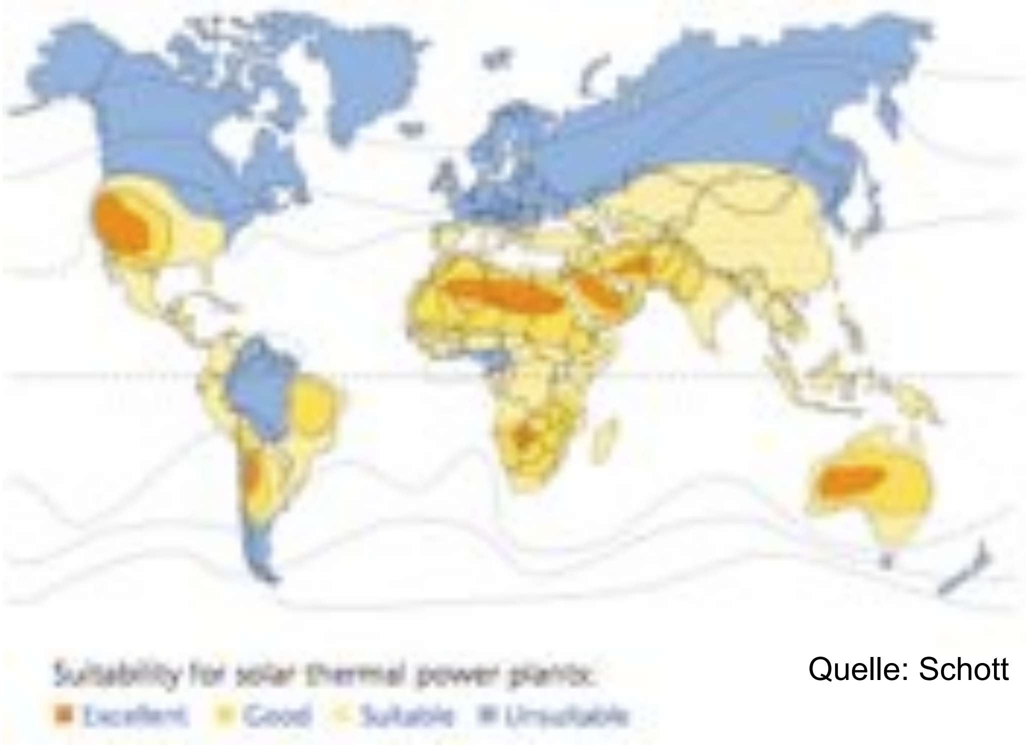
- Digital electronic needs power and needs cooling
- Running costs probably dominated by energy costs
- Site is far away from civilisation centres and power grid



- Different power requirements – energy mix!
  - Core(s): ~30 to 50 MW
  - HPC centre near core: ca. 50 MW
  - Distant stations: each ~100 kW for ca. 80 stations
  - Differences in peak and average demand (Electronic, cooling, telescope movements)
- Continuous operation 24/7: Storage required?!
- Avoid variations in power supply: power stability
- Environment: Temperature changes, wind, rain

Power supply: Solar Energy?

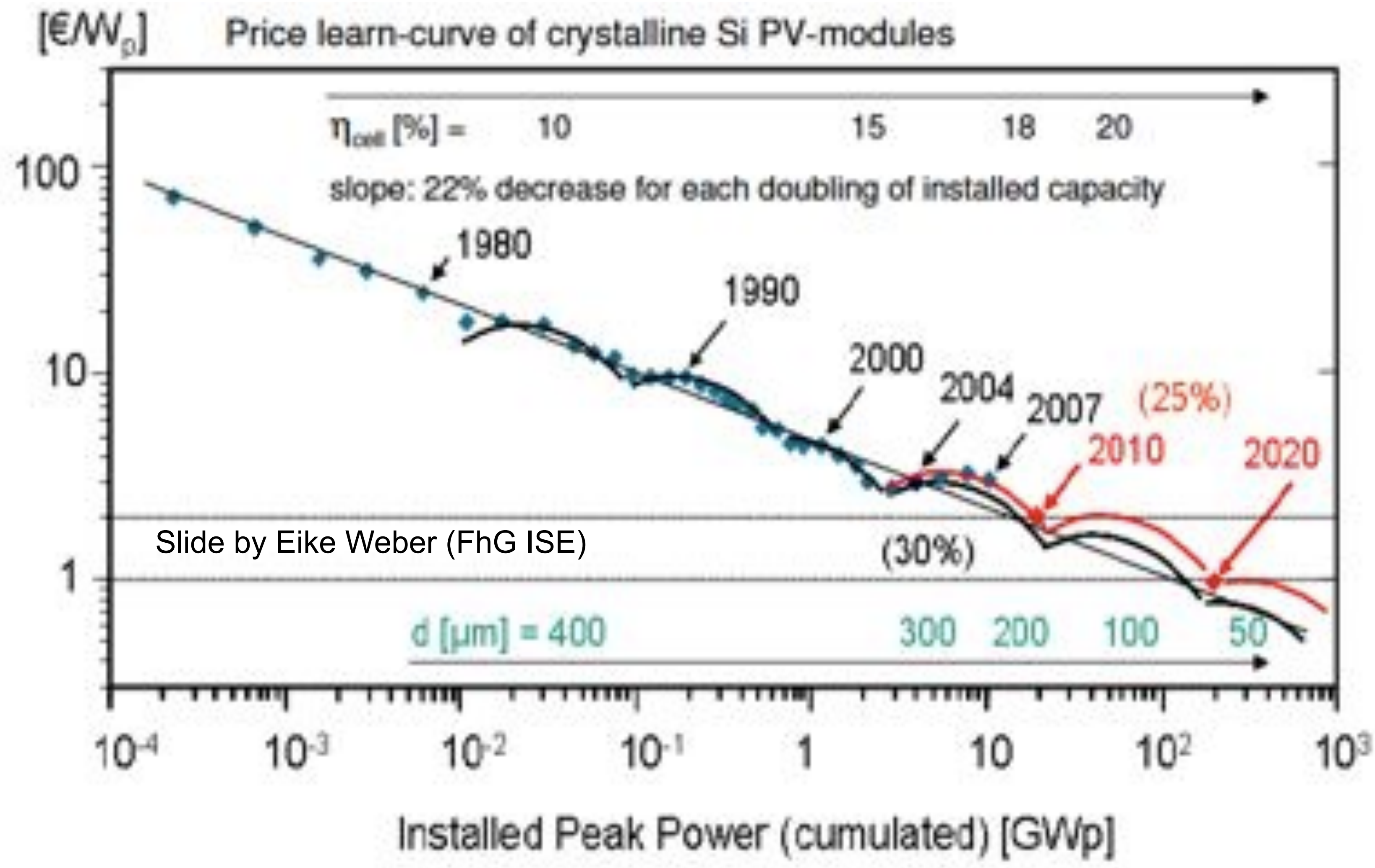
- Supply with solar energy obvious and best (and only?) solution ?



Quelle: Schott

- Excellent light house project for renewable energies (already for "SKA Pathfinders")
- Sustainable energy solution for the whole life time (~50 year)
- Opportunities to open new markets.

Green astronomy, Green SKA



- SKA will drive innovative solutions in generation, distribution, efficiency and demand reduction in a harsh environment.
- The largest challenge is the storage for 24/7 operation

Vision in partnership with Fraunhofer ISE

SKA as lighthouse project for future Mega-Science Projects

World-class sciecne with 100% renewable energy and 0% carbon footprint:

Fraunhofer ISE

CSIRO

Workshop on
"Renewable Energy Concepts for mega-Science Projects demonstrated at the SKA and its Pathfinders"

April 7, 2011

Wissenschaftsforum Berlin Mitte

Workshop, 7. April 2011,
Signing MoU: MPIfR/ISE/CSIRO

NB. Australia is pushing renewable, as it is nuclear free and fossil fuels are no option

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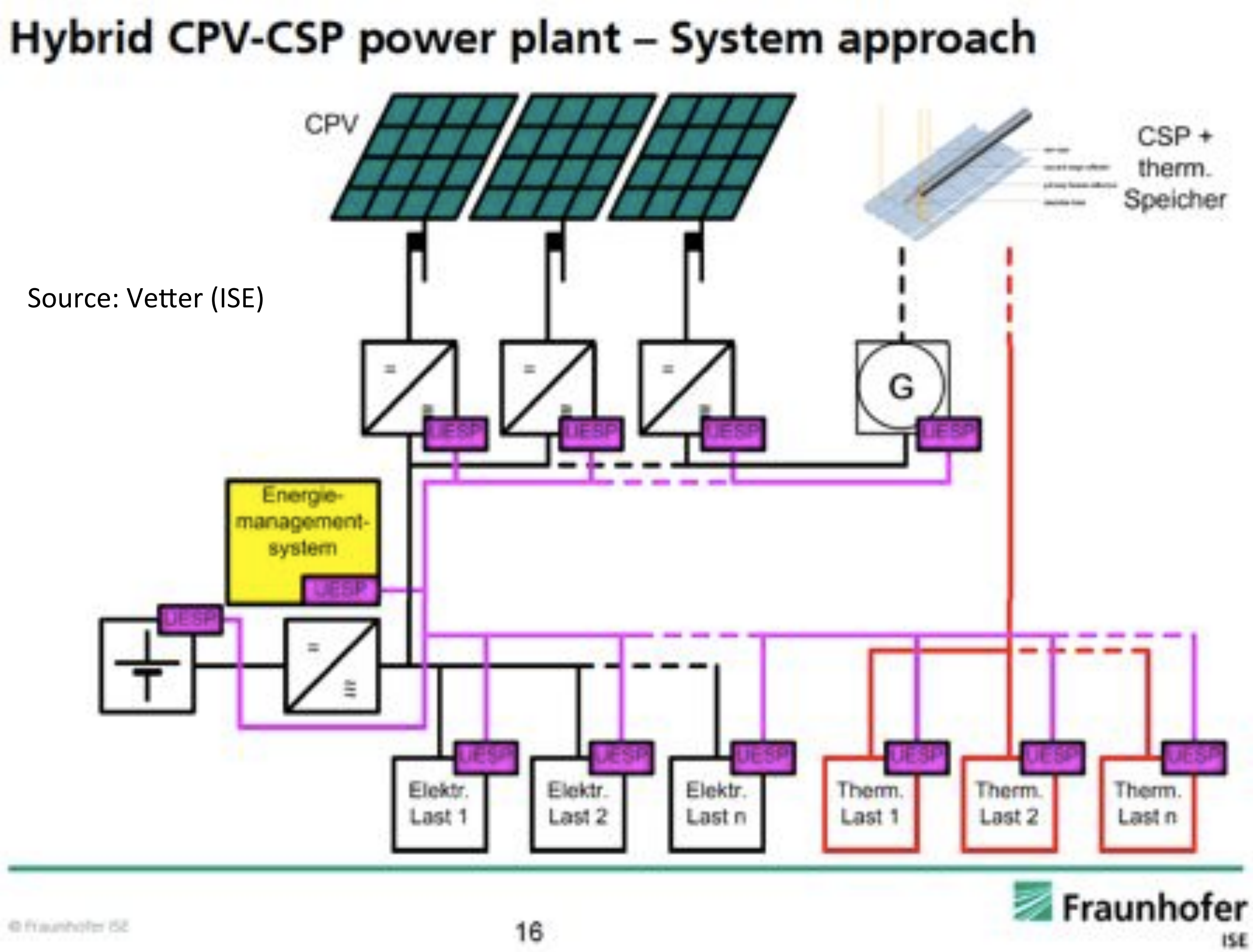
One possible energy concept



Source: Vetter (ISE)

However, with different requirements at SKA core and remote stations
a mix (100kW – 50 MW) is required

Testing systems on the ground

- It has not been fully agreed that the SKA is to be powered by renewable energy (Costs!) Solar power and alternatives are currently studied by „Power Investigation Task Force“
- However, adopting a scheme which will make the SKA the largest “green” scientific megaproject with lessons for every one

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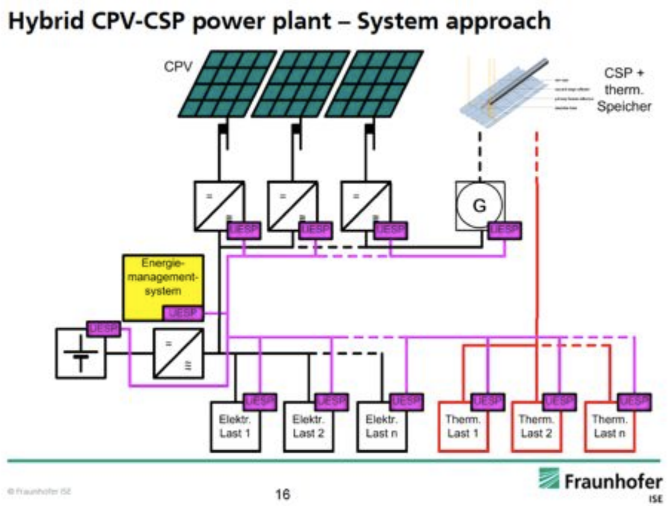
1. CSIRO contracted FHG ISE/MPIfR for initial planning of solar energy solution for ASKAP



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2. Aperture Verification Programme (AAVP) tests hardware in a radio quiet area in Portugal Site will also serve as a test site using solar energies in combination with the power grid for the AAVP.

Nearby the Moura Solar Photovoltaic plant.
generating over 60MW with 350.000sqm solar cells over 1000 solar trackers,

Challenges and ways to make it possible

- Don‘t shoot yourself in the foot:

  - The SKA will be ultra-sensitive – we must avoid producing Radio Frequency Intereference on our own, NB:

    Mobile on the phone = 3rd brightest radio source

  - Balance between power transport, power electronic, losses

- Try to reduce power requirements from the start (green HPC, low-power devices, efficient architecture)
- Use combination of technologies,

  e.g. add geo-thermal cooling
- Develop effective, efficient and inexpensive storage solution

- Involve industry! – New Markets: 1.6 Billion people without access to power grid!!

- Use the public attraction of astronomy!

Public is very keen to be involved: An Example...

Conclusions

- The SKA will be a game-changing observatory producing stunning science
- It can serve as a lighthouse project to demonstrate 24/7 operation with 100% renewable energy independent of grid-solutions
- It can be a prime example for sustainable Mega-Science with 0%-Carbon Footprint
- With astronomy (and SKA's Key Science, e.g. Einstein, Black Holes ..) appealing enormously to the public, the SKA can break ground for other projects
- Required energy mix (mini-grid solutions with storage) is likely to produce solutions for many applications
- Key to the success of a 100% RE-SKA will be the development of innovative systems solutions: PV, CPV, CST solar power, wind if available, plus storage
- It is not clear whether we can afford it, but "Green Astronomy" is likely to be spectacularly popular
- In any case, we may not be able to afford to pollute the Earth for the exploration of the Cosmos

It is not easy – but we should certainly try it!

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Exploring the Universe with the
world's largest radio telescope

www.skatelescope.org