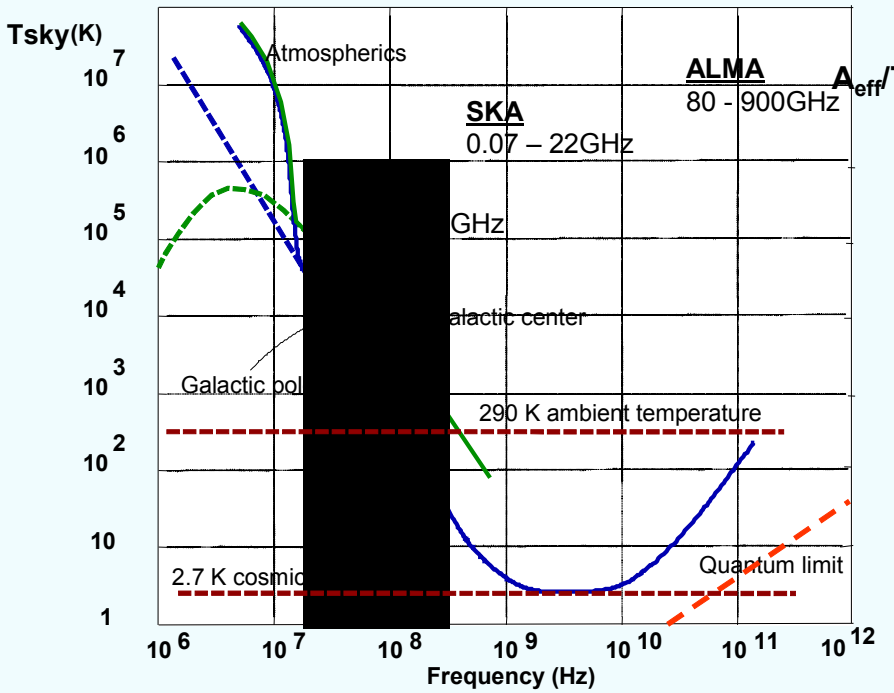
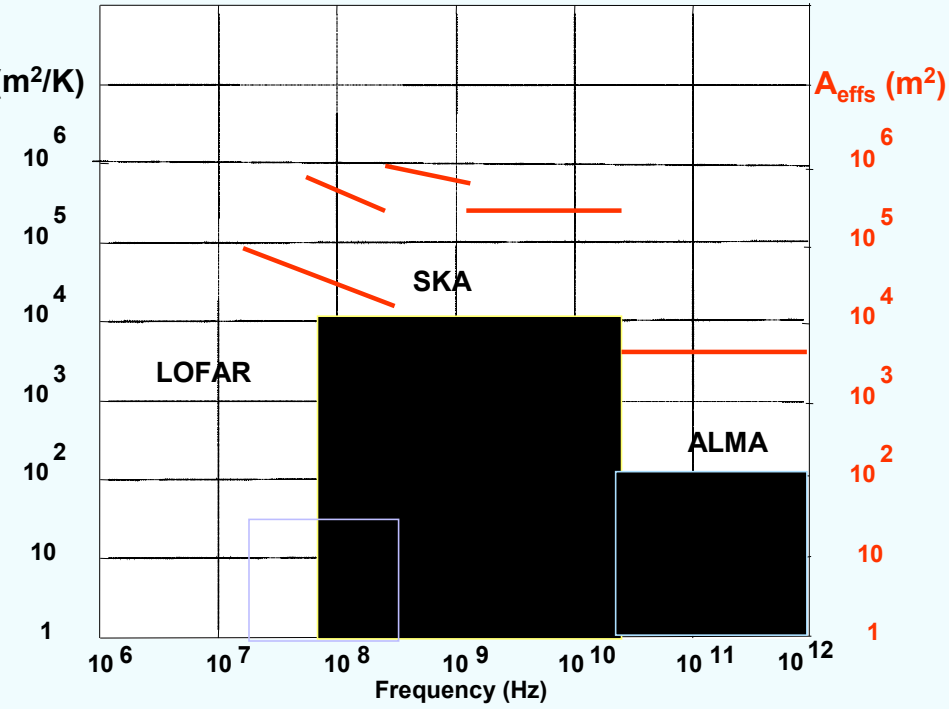
The Square Kilometre Array and its Precursors

Arnold van Ardenne

Courtesy: Richard Schilizzi and many collegues

Radio Astronomy re-invented: "new" major observing facilities...



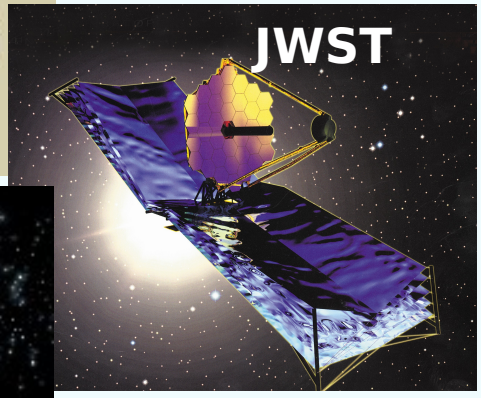


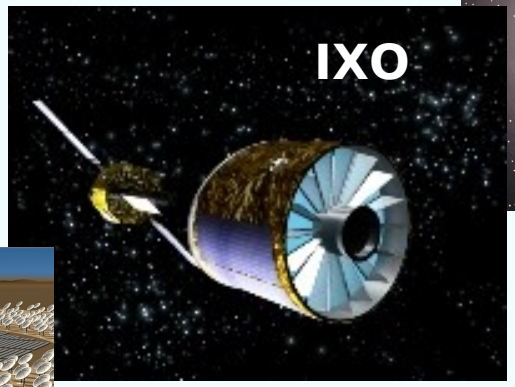
Sky noise temperature and sensitivity vs. Frequency

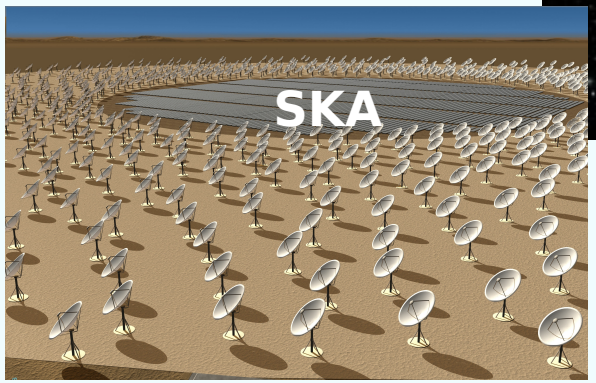
Big questions in astrophysics and cosmology

- **How and when did the first stars and galaxies form in the universe?**
- **What is the mysterious dark energy and dark matter that fill the universe?**
- **How did the universe, and the galaxies in it, evolve?**
- **Was Einstein always right about Gravity?**
- **Where did the magnetic fields in the universe come from?**
- **Is there life of any sort anywhere else in the universe, and is it intelligent (like us?)**

Instruments to answer these questions







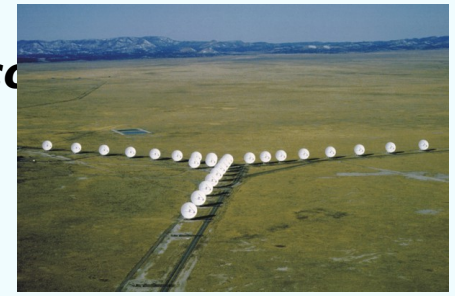
Europe: SKA on (updated) ESFRI (Dec 2008)& ASTRONET (Nov 2008) Roadmaps

US: 2010-2020 Decadal Report Process started

Astronomy in the Radio: The Square Kilometre Array

4 prime characteristics

- *very large collecting area (km²)* → sensitivity to detect and image hydrogen in the early universe
  - ***sensitivity ~ 50 x most powerful current telesco (EVLA, LOFAR)***



- *Very large field of view* → fast surveying capability over the whole sky
  - ***survey speed ~10^4– 2 x10^6 x EVLA***

- *wide frequency range required for the Reference Science Mission*

  low : 70-300 MHz
  mid: 300 MHz-10 GHz
  high: 10-25+ GHz

- *large physical extent (3000+ km)* → capability for detailed imaging of compact objects and astrometry with milli-arcsec angular resolution

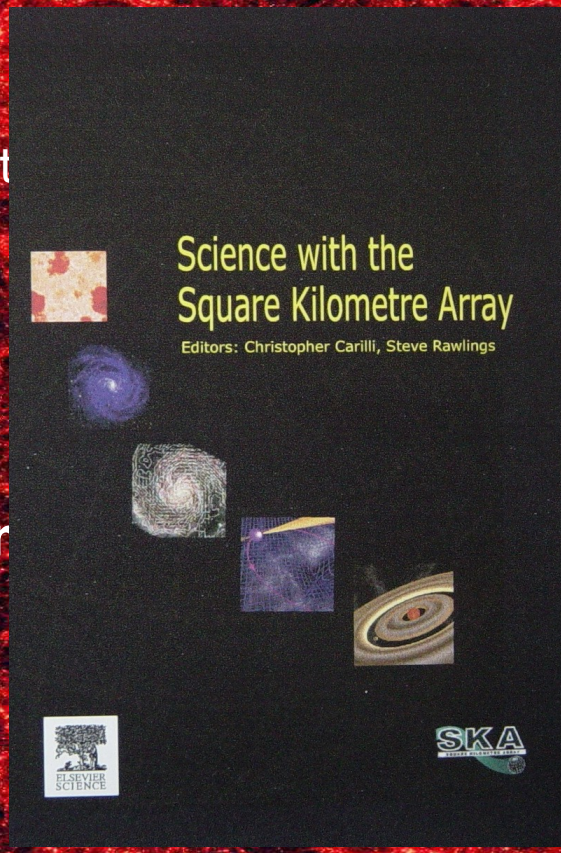
SKA Key Science Drivers

ORIGINS

- **Cosmology and Galaxy Evolution**
  Galaxies, Dark Energy and Dark Matter
- **Probing the Dark Ages**
  When & how were the first stars formed?
- **Cradle of Life**
  What are the conditions for life and where can it be found?

FUNDAMENTAL FORCES

- **Strong-field tests of General Relativity**
  Was Einstein correct?
- **Origin & Evolution of Cosmic Magnetism**
  Where does magnetism come from?

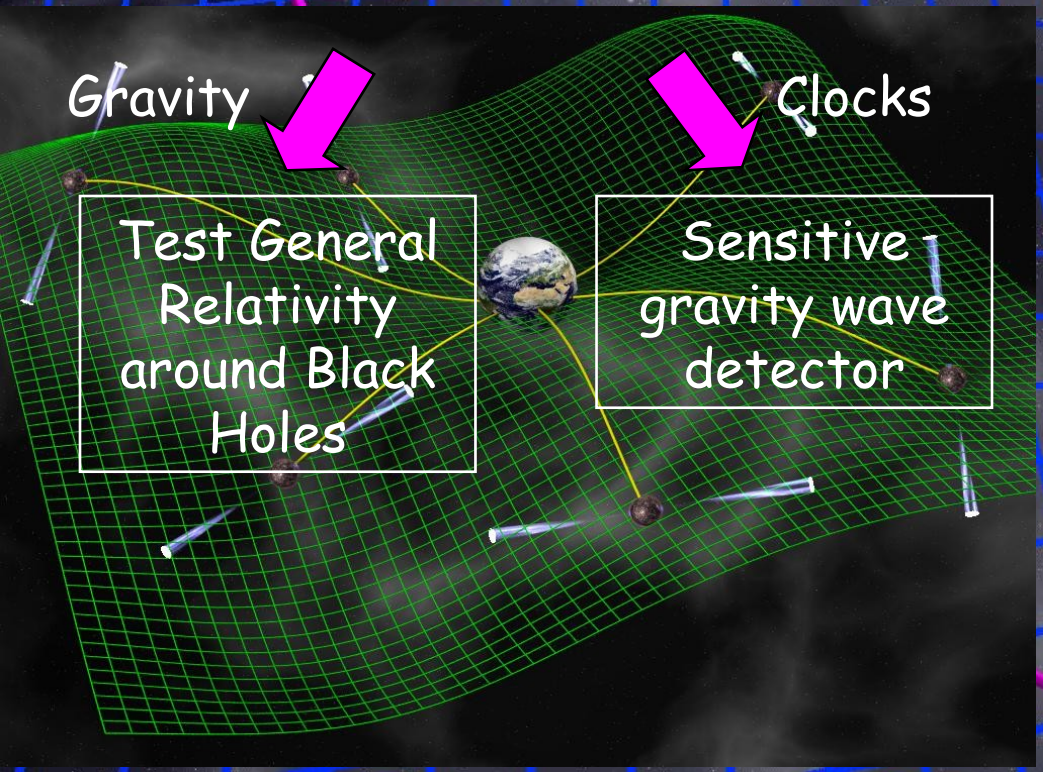


plus **The Exploration of the Unknown** as an underlying philosophy for design & costing

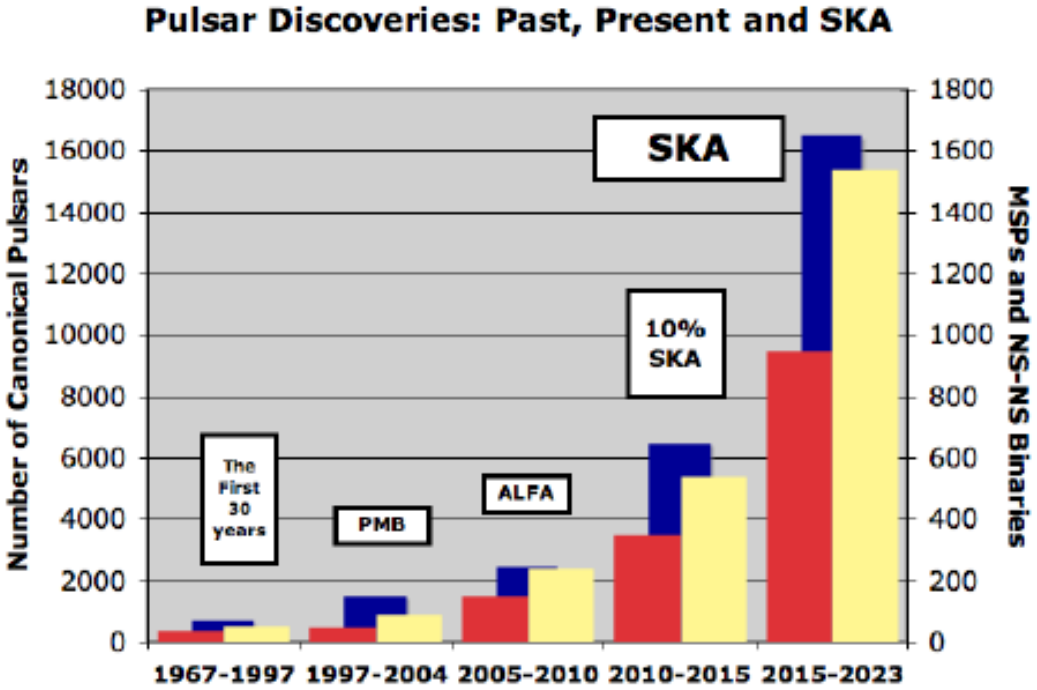
Strong field tests of gravit

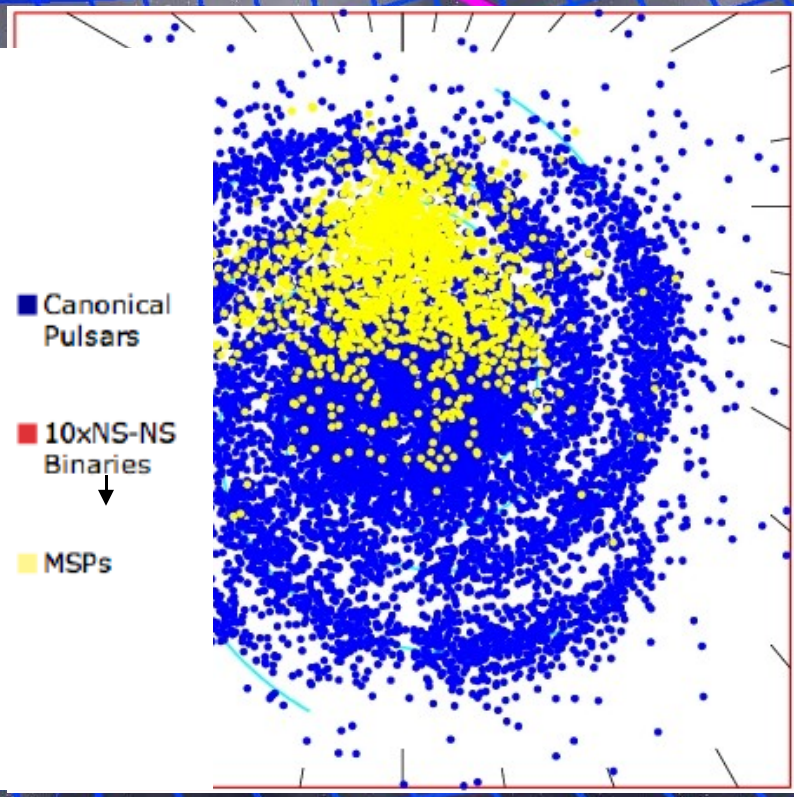
SKA as Pulsar Timing Array

Identify and time pulsars
with nano-second accuracy



SKA will find ~20000 pulsars in our Galaxy

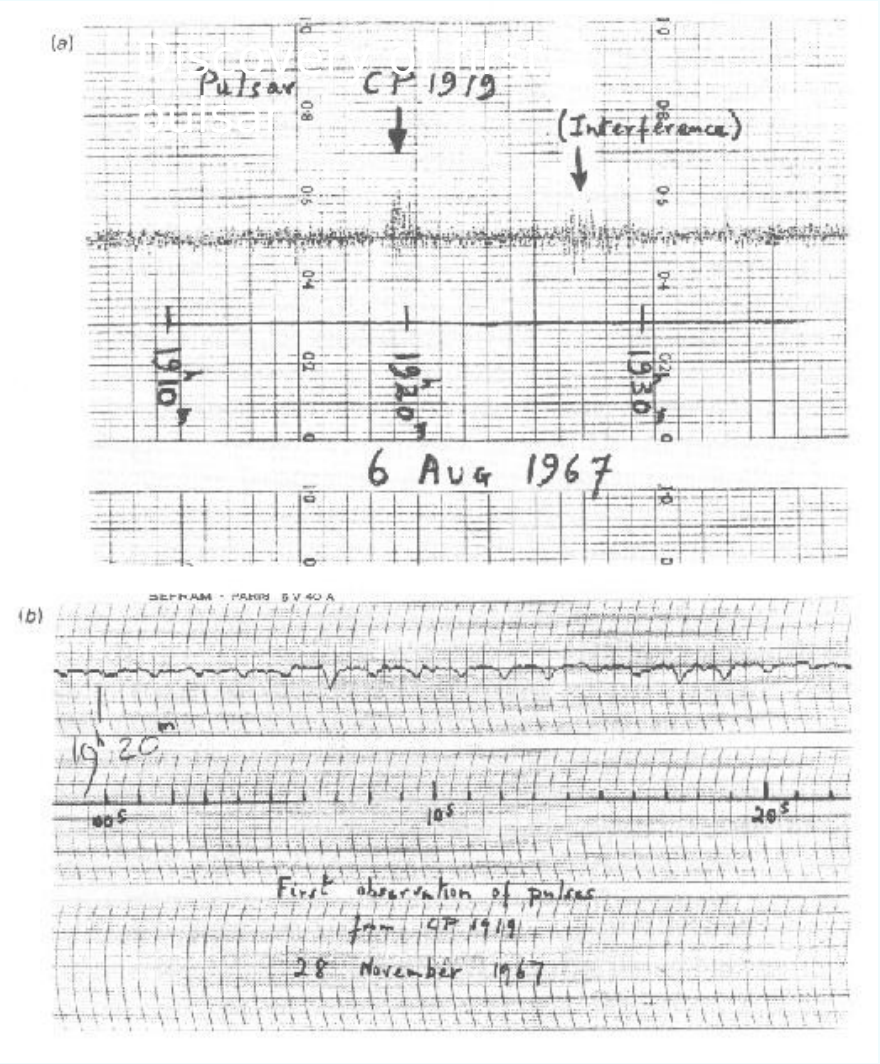




Exploration of the unknown

- **Unplanned discoveries**
  - Pulsars
  - Microwave Background
  - Cosmic Evolution
  - Dark Matter in galaxies
  - Quasars
  - Jets + Superluminal motion
- **Transients**
  - Detailed Gamma ray burst afterglows
  - Others, be surprised.....

Reading suggestion:
`The Black Swan'
Nassim N.Taleb



Pulsars as observed first

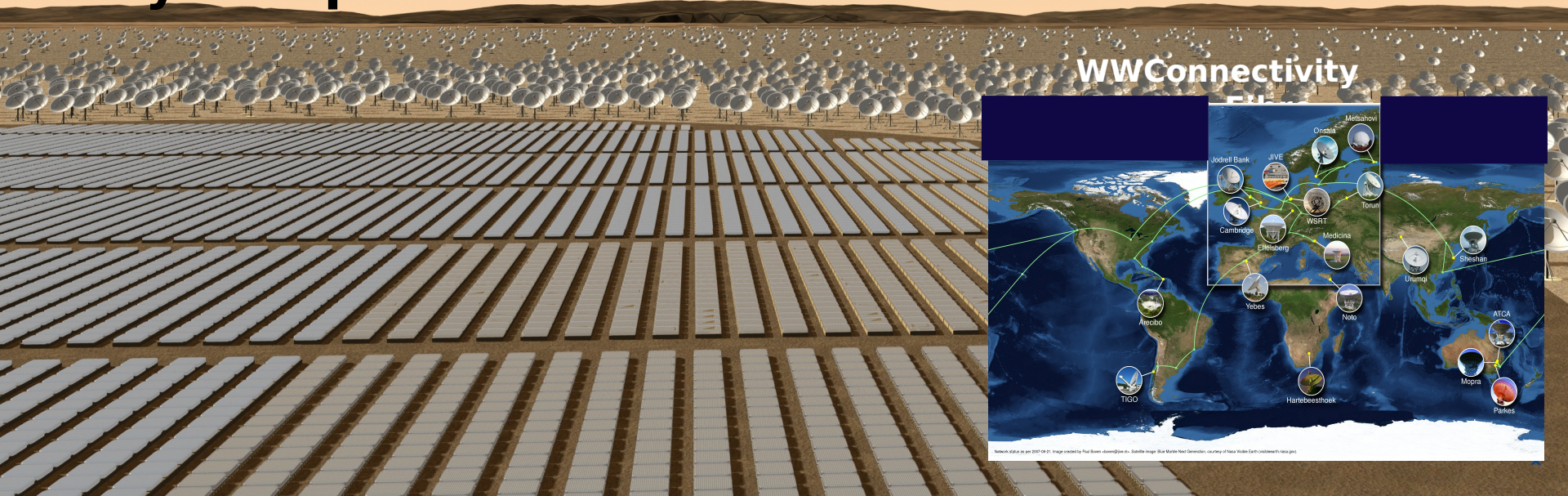
Artist's impression of the SKA

1000- 1500 dishes (15m) in the central 5 km 2000-3000 total

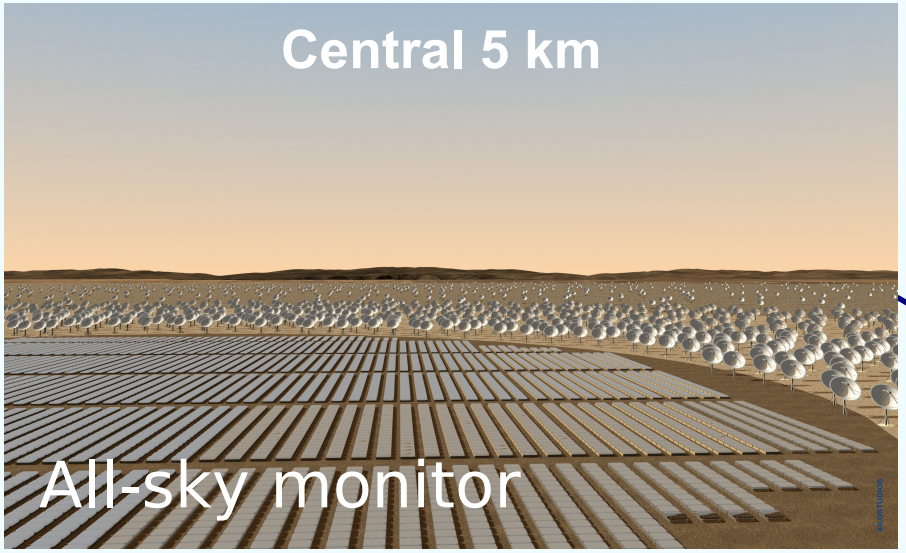
+

dense and/or sparse aperture arrays

connected to a massive data processor by an optical fibre network

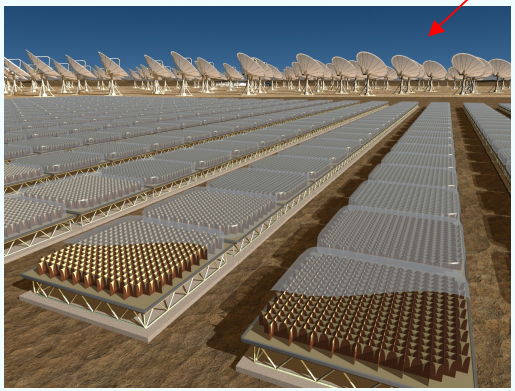


SKA; Reference Design

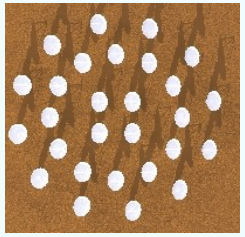


Stations to
3000 km

Central core with
1000-1500 dishes (15m) (2000-3000 total)
+
Dense and/or sparse arrays



Interferometer array connected to a massive data processor through fiber optics network



Station

Reference design

(SKA R&D has been going on since ~1995)

- **Interferometer array of sensors centred on a massive data processor**

- **Sensor types**
  - **Dishes + wide band single pixel feeds *(baseline)***
    (mid-band + high-band)
  - **Dishes + multi-pixel phased array feeds**
    (mid-band)
  - **Aperture arrays**
    (low-band, mid-band)

Dishes+Single Pixel Feeds

USA

ATA 6m hydroformed dish

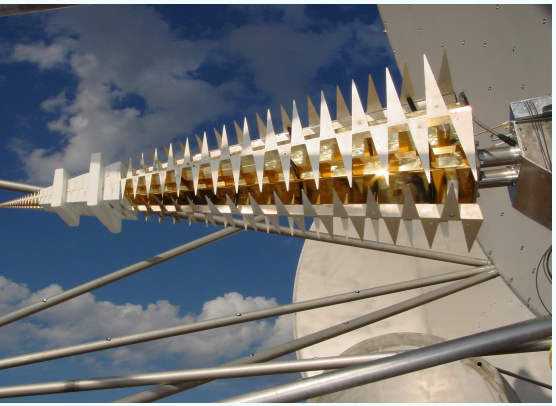
South Africa

15 m composite dish

Canada

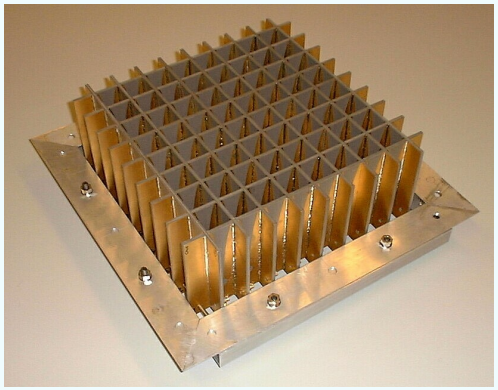
10 m composite dish

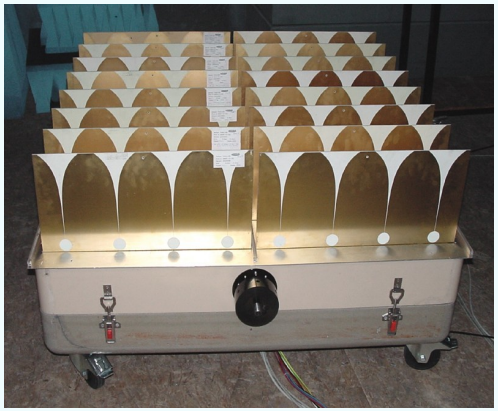
Example Novel Wideband feeds for astronomy



Piramidal log per.
0.5-12GHz
UCB Radio Labs
Courtesy Jack Welch

“Eleven”feed
0.15-2GHz and 1-13GHz
Courtesy Per Simon Kyldal
Chalmers Techn. Univ. Gothenburg
Also: For “MeerKAT/S.A.”



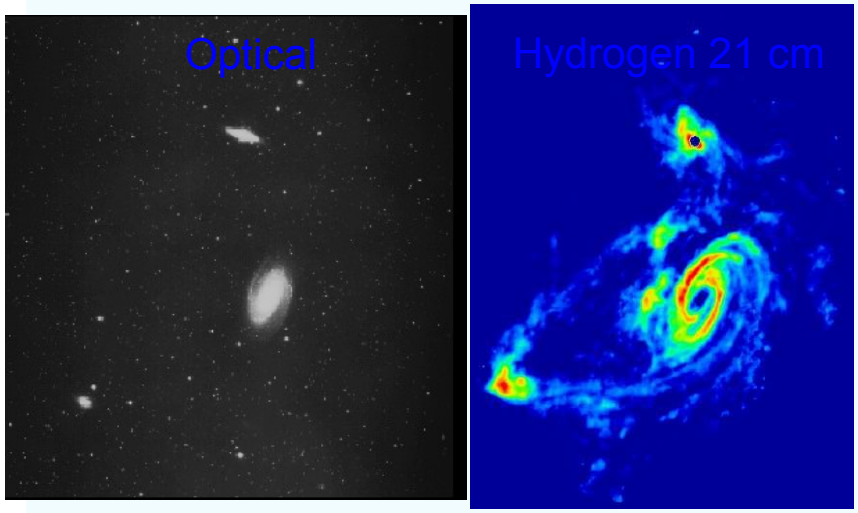


“dense” Vivaldi Arrays 2- 7 GHz and
0.5- 1.7GHz UMass, ASTRON
Courtesy Dan Schaubert
and ASTRON

Imaging advances in Radio Astronomy

Angular resolution (θ = λ/ D)

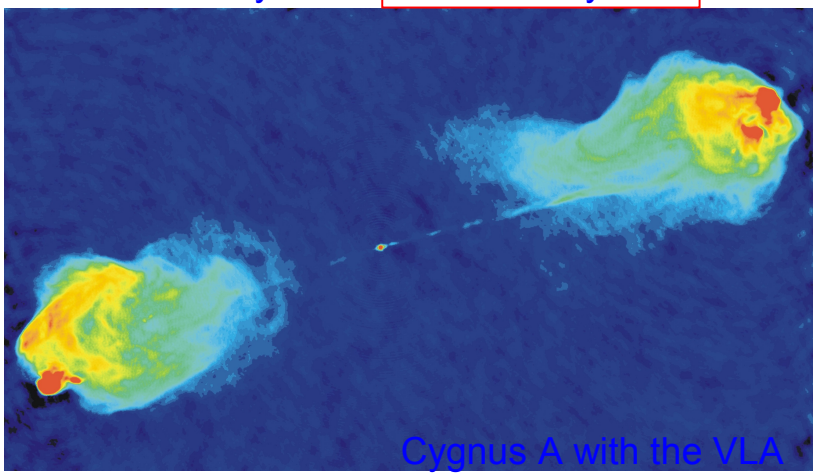
- Dwingeloo 25m @ 21cm 0.5deg
- Effelsberg/GBT 100m @ 21 cm 8'
- Westerbork-SRT 2500m @ 21 cm 15"
- Very Large Array 30km @ 2cm 0.15"
- SKA/VLBI 1000km @ 3cm 4milli" ***~ELT/VLTI-IR***
- Space VLBI 400.000km @ 6cm 20μ"
- mm VLBI 10.000km @ 350GHz 15μ"



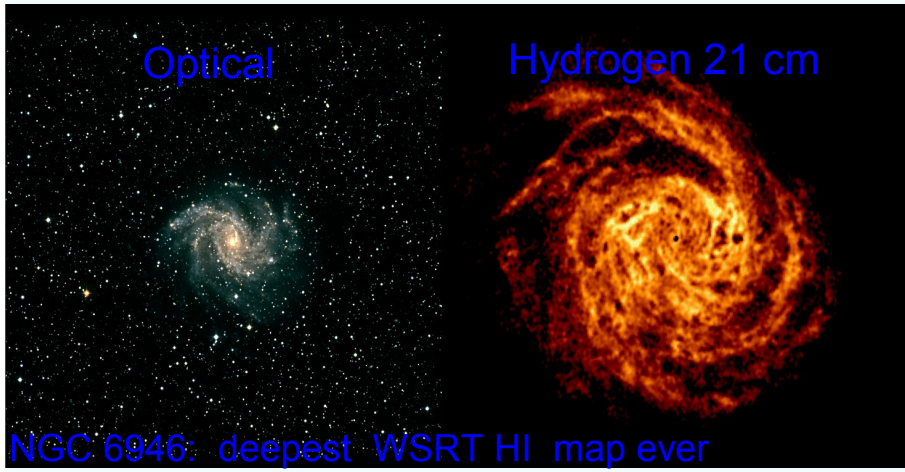
Messier 81 in the Big Dipper

Improvement AngRes ~10^7x in 50 years

- Improved calibration and processing e.g. M.E.
- Improved Sensitivity ~10^5x in 50 years



Cygnus A with the VLA



NGC 6946: deepest WSRT HI map ever (16x12h)

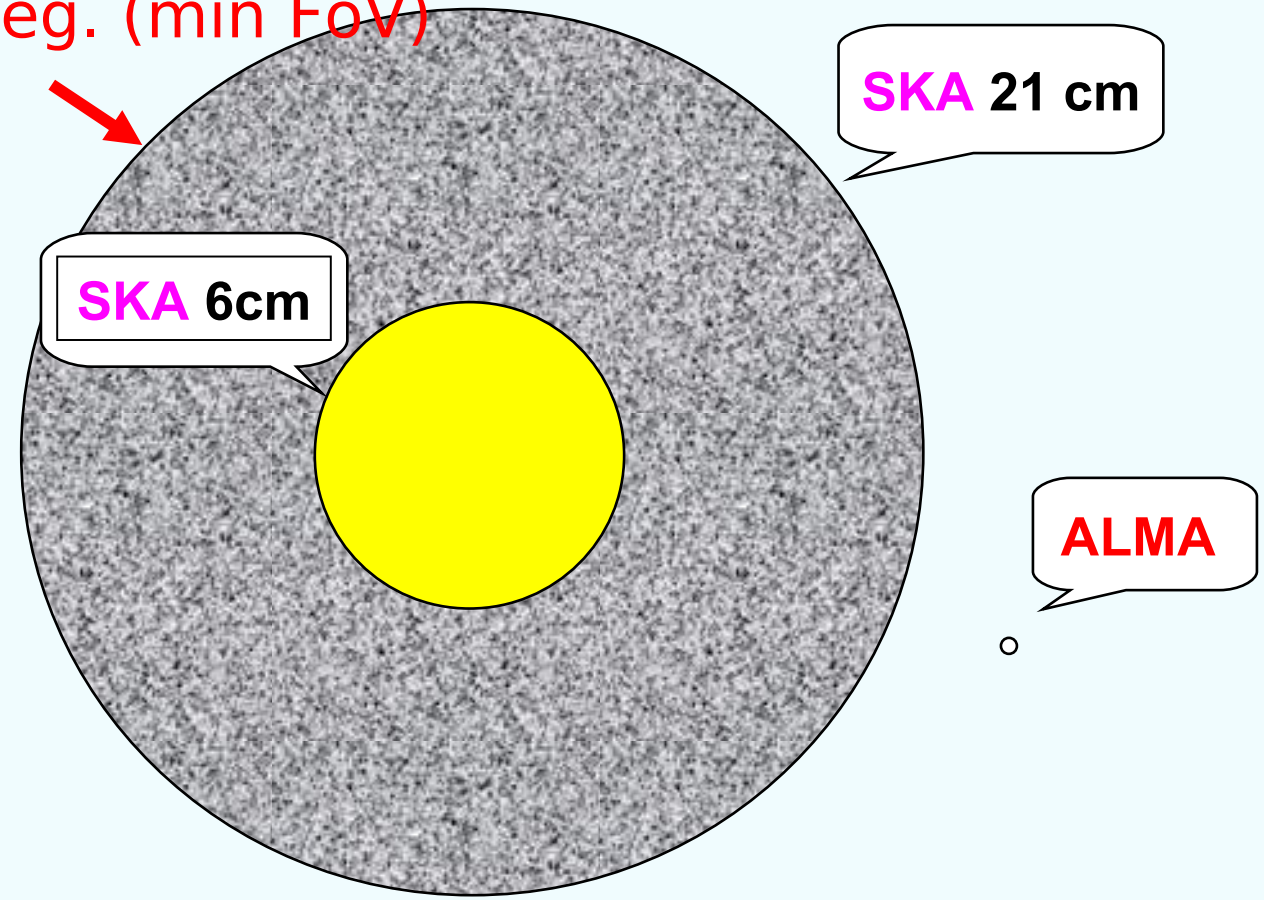
- ***Result: High Dynamic range ("clean") images***

Very large field of view

1 sq. deg. (min FoV)

20 sq. deg. for Phased Array receivers like Apertif & ASKAP

200 sq.deg.for Aperture Arrays



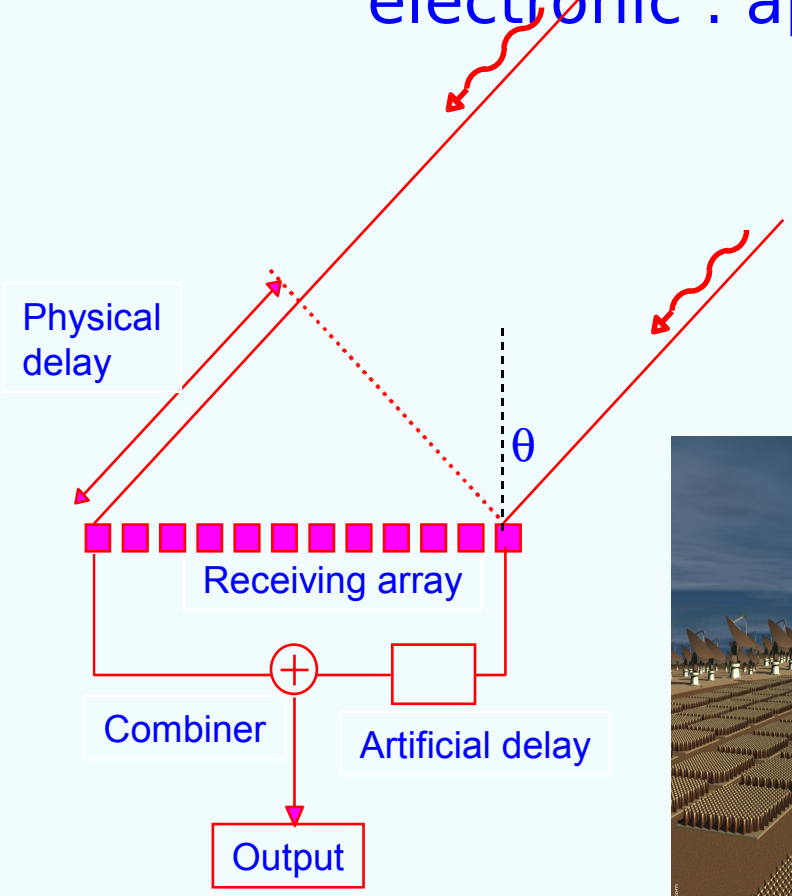
The Moon (same scale)

ALMA=Atacama Large Millimetre Array

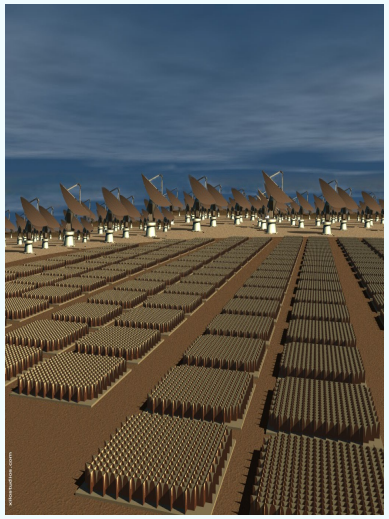
Next step: Expanding FOV; Arrays and paraboloids

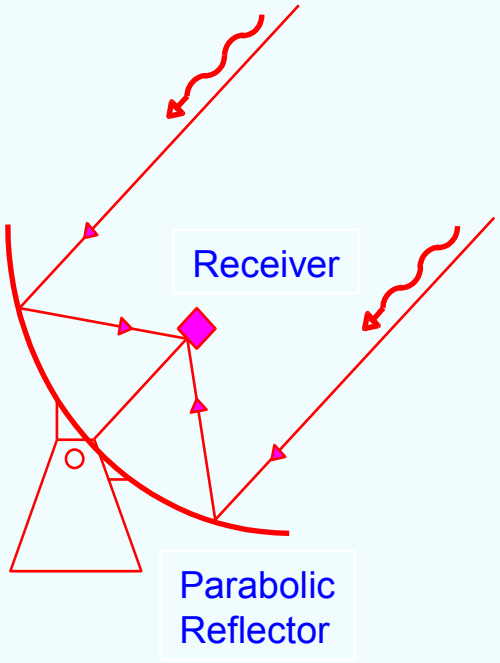
electronic : aperture array

mechanical: paraboloid



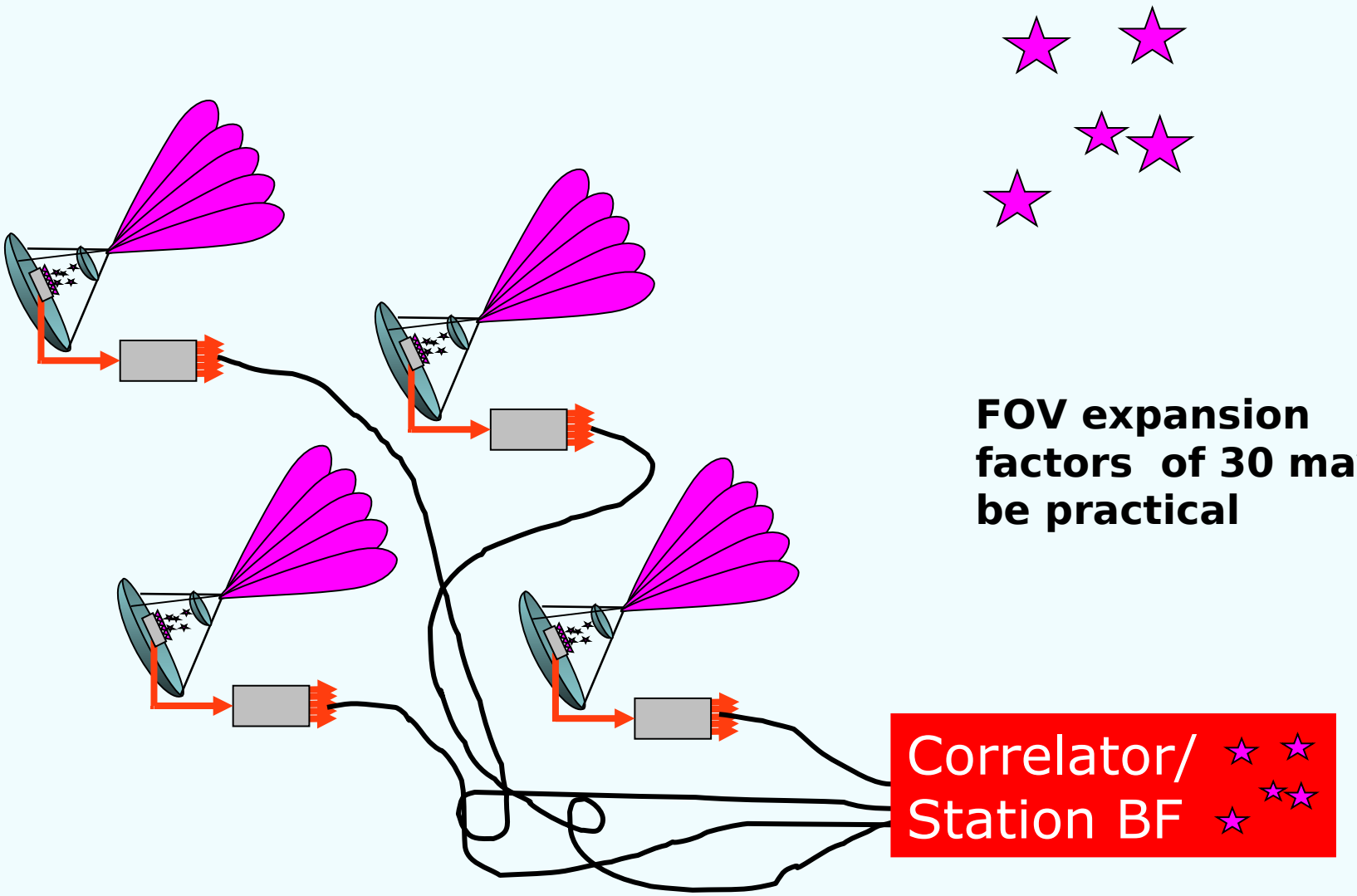
(a): Electronic pointing





(b): mechanical pointing

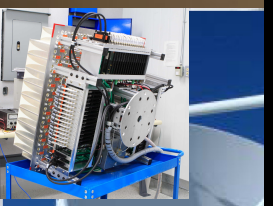
Multi-pixel beam-formimg

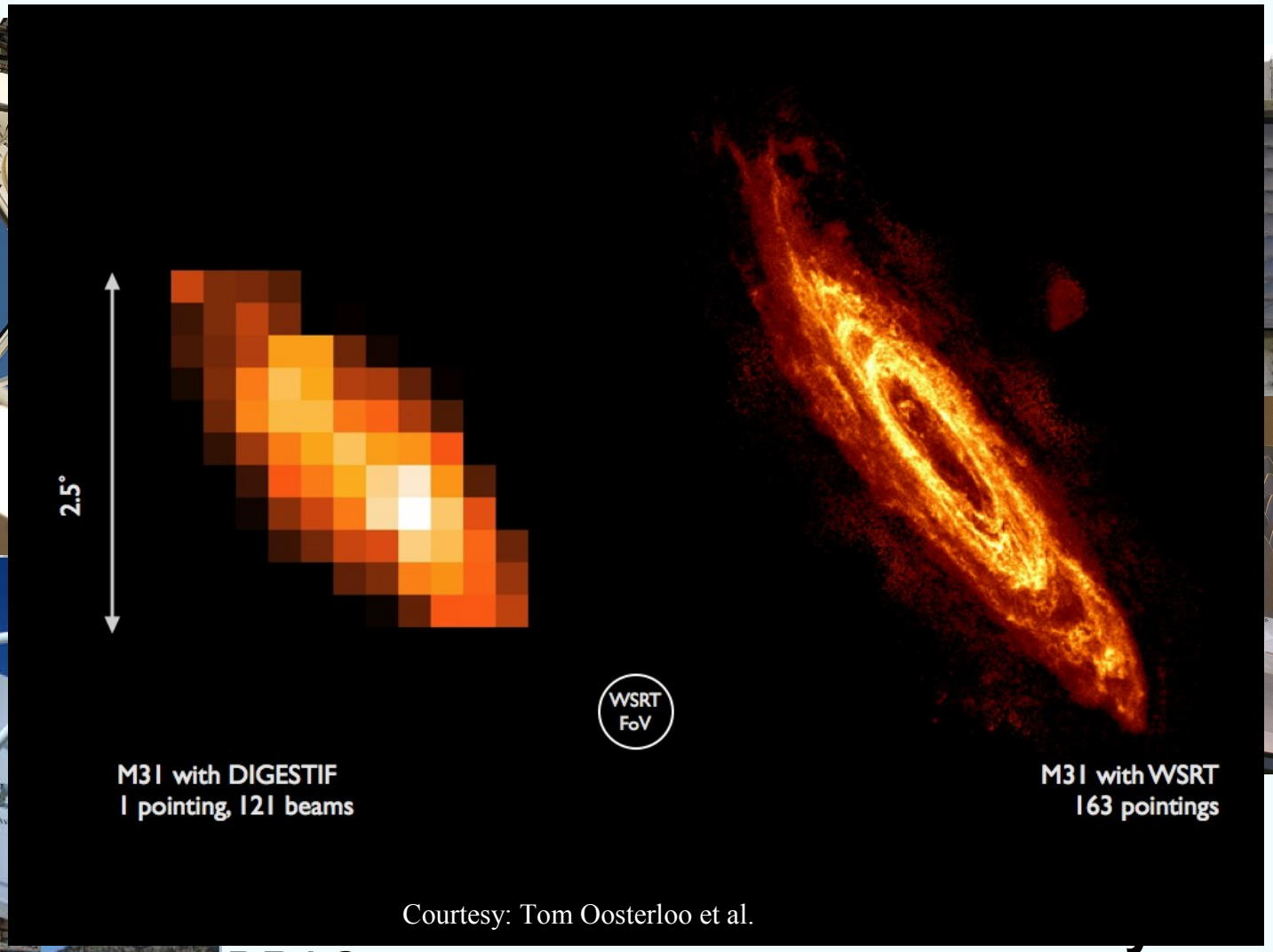


FOV expansion factors of 30 may be practical

An alternative view…..

Dishes+Phased Array Feeds





Courtesy: Tom Oosterloo et al.

DRAO
Canada

Large Field of View Radio Astronomy

SKA Key Science Drivers

ORIGINS

- **Probing the Dark Ages**
  When & how were the first stars formed?
- **Cosmology and Galaxy Evolution**
  Galaxies, Dark Energy and Dark Matter
- **Cradle of Life**
  What and where are the conditions for life?

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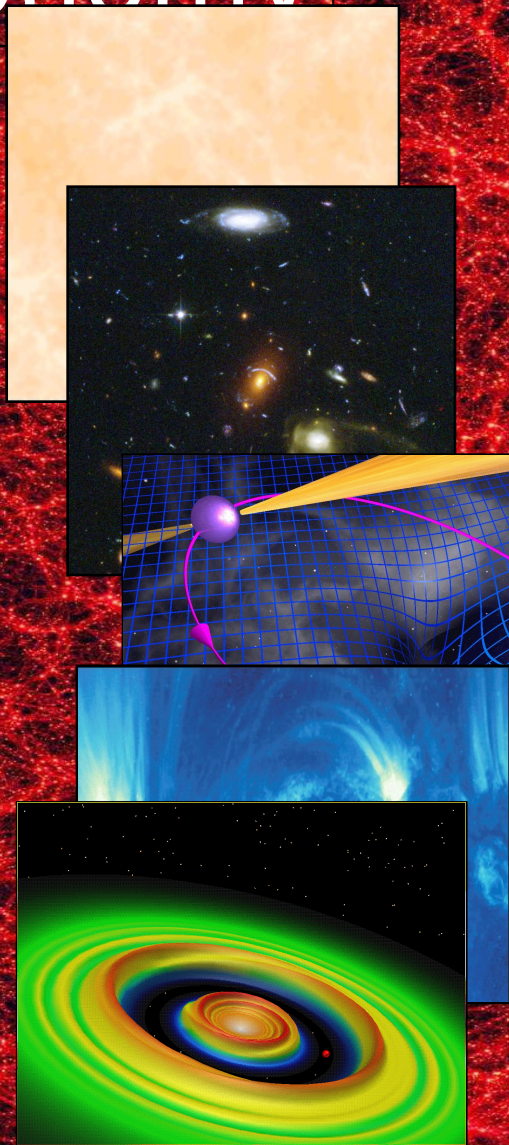
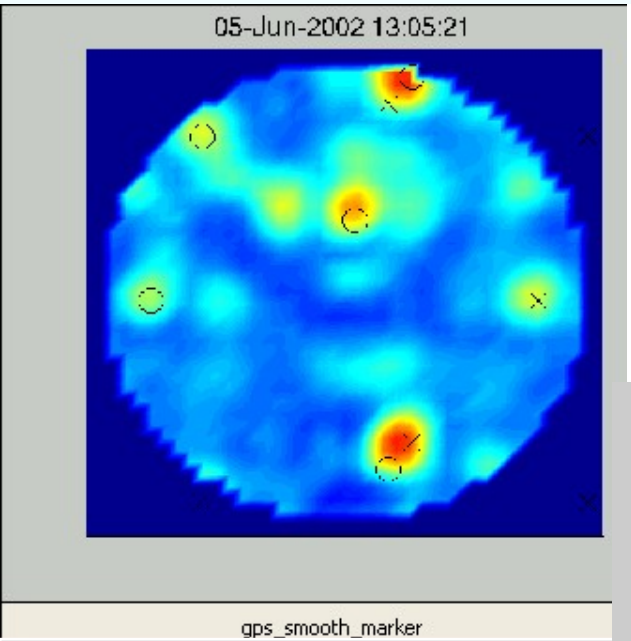
  Was Einstein correct?
- **Origin & Evolution of Cosmic Magnetism**
  Where does magnetism come from?

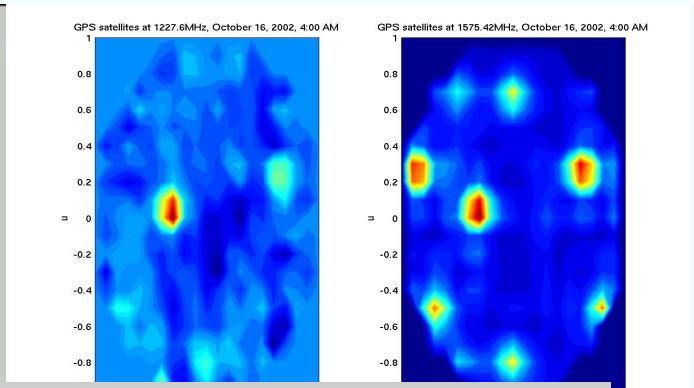
plus **The Exploration of the Unknown** as an underlying philosophy for design & costing

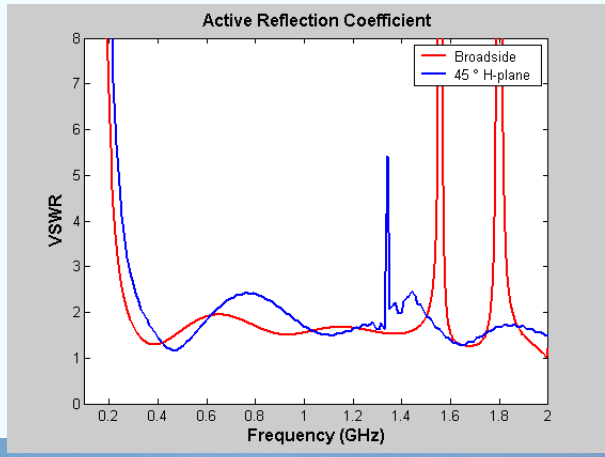


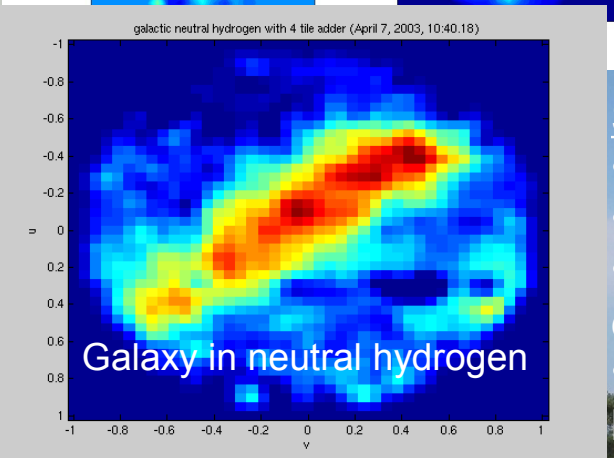
(see also www.skatelescope.org)

Multibeaming with Dense Arrays: Demonstrated to work…

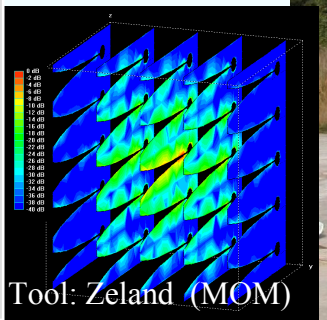








- GPS satellite's @ 1575MHz
- Scan's every 9 minutes
- Grating lobs marked with cross:
  λ/2 = 1.2 GHz
- ''More'' RFI visible
- One tile

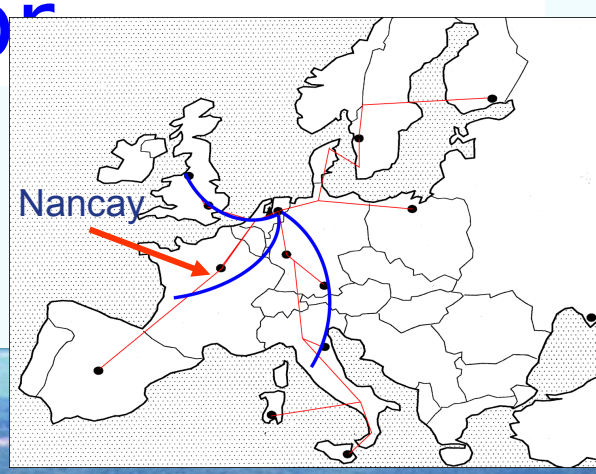


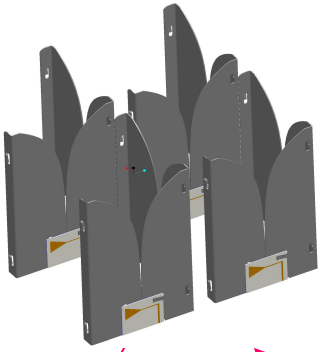
Some THEA specs:

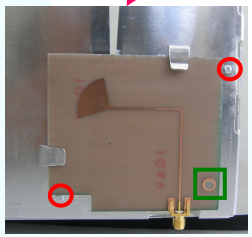
- 1024 elements, 256 active
- Frequency range: 500- 1700 MHz
- 2 independent RF beams, 8 digital beams
- Adaptive beamforming (RF/tile level & digital/ adaptive)
- Outdoor facility etc.

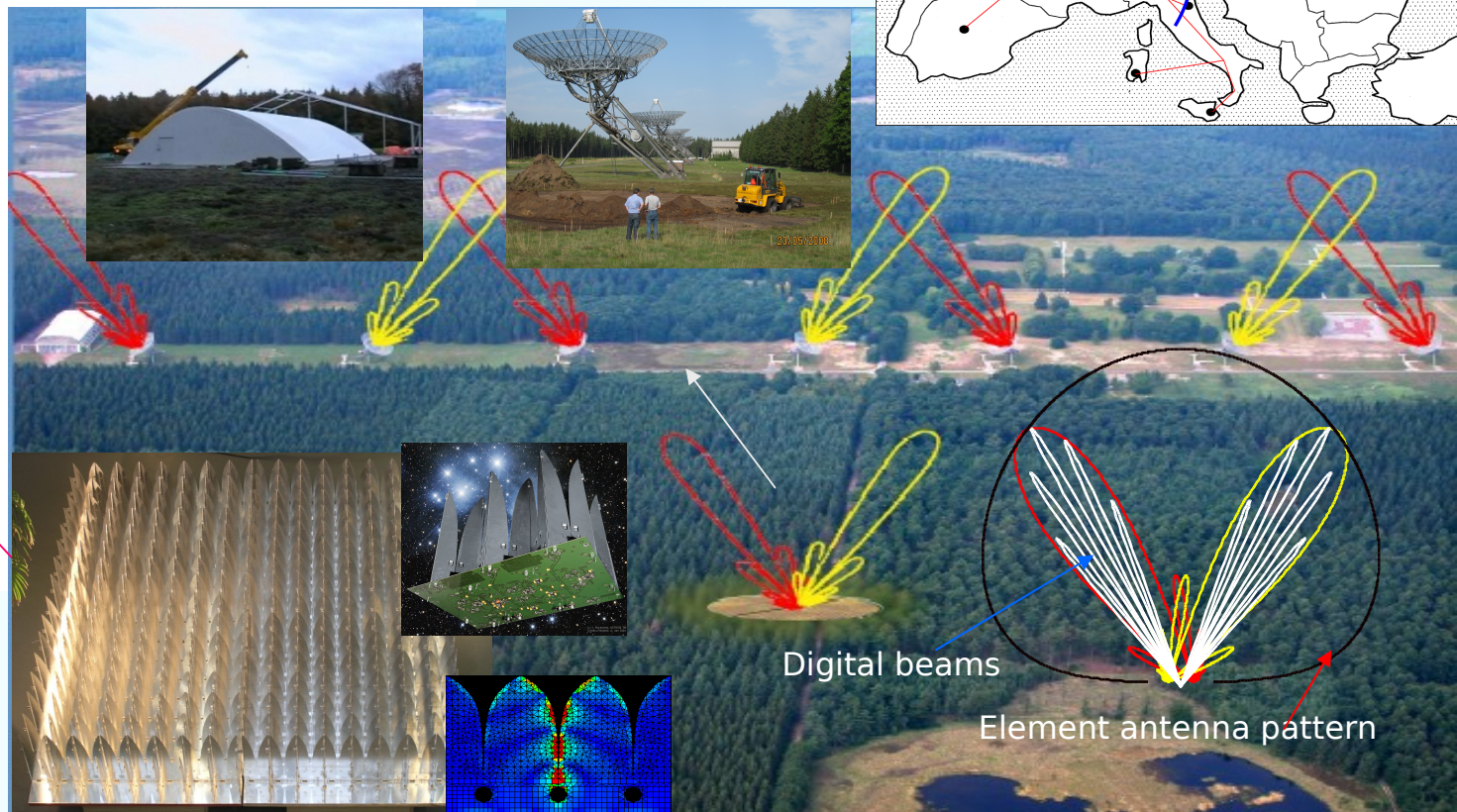
EMBRACE; a world-first SKADS onstrator

- 200+100m² at two locations Westerbork and Nancay
- Frequency range: 450- 1500 MHz
- 2 independent FOV´s beams, 4 digital beams/FOV
- Adaptive beamforming (deterministic & adaptive)
- Station Processing ~5-10 Tops/sec









Sparse aperture arrays for the lowest frequencies

LOFAR (Netherlands et al)

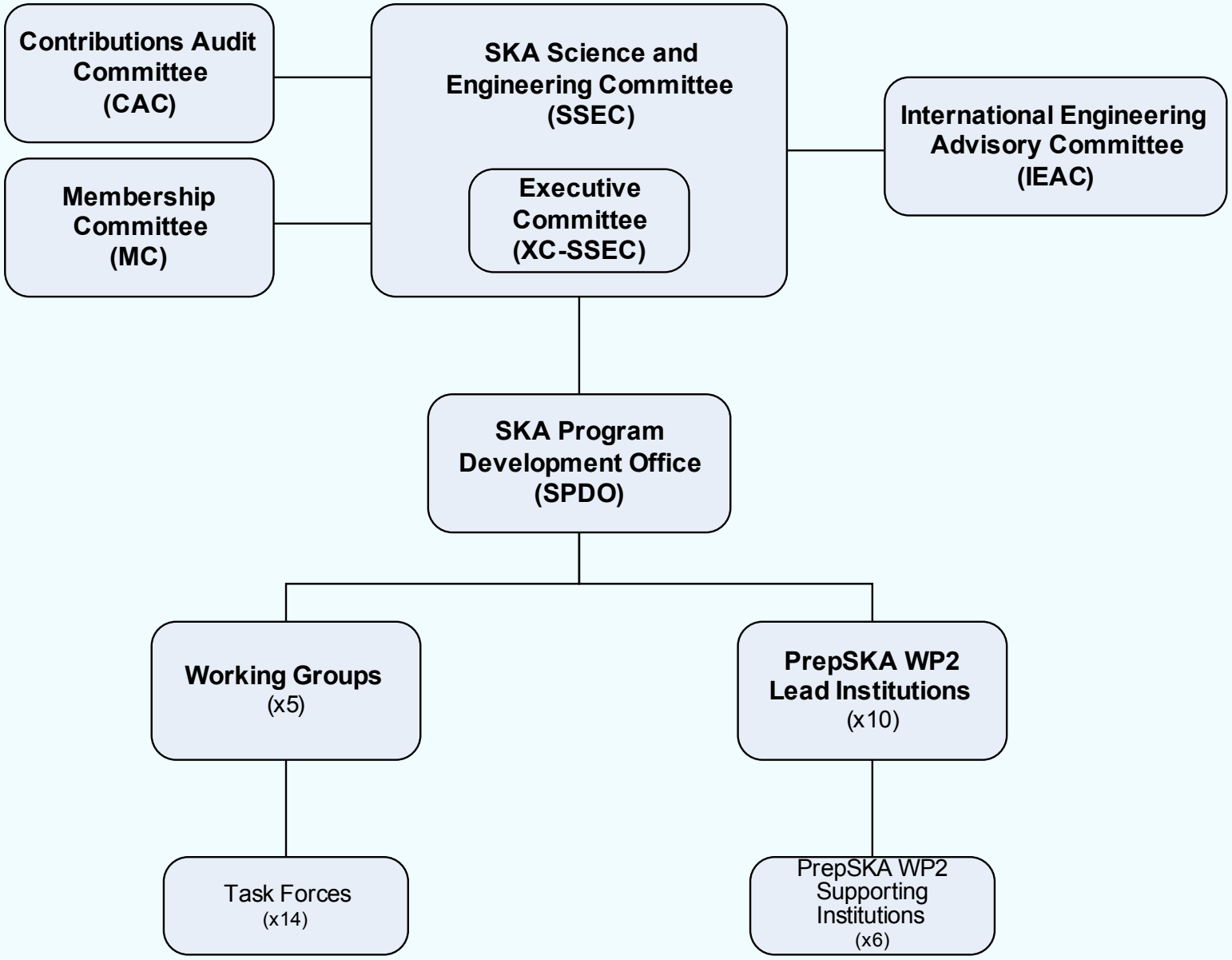
Activities today

LWA (USA)

SKA: 70 - ~300MHz

MWA (USA, Australia)

International organisation



Costs

- **Target construction cost: 1.5 billion € for Phases 1+2**
- **Expected operating costs: 100+ million €/year**
  - Energy costs a big contributing factor
- **Currently funded SKA R&D (2007-2012) via national and regional projects: 140 M€**
  - PrepSKA (FP7) funds the SPDO engineering team
  - Design Studies (FP6 SKA Design Study, US Tech Dev Program)
  - Pathfinders (ASKAP, MeerKAT, LOFAR, Apertif, ATA, MWA, LWA, EVLA, eMERLIN, eEVN)

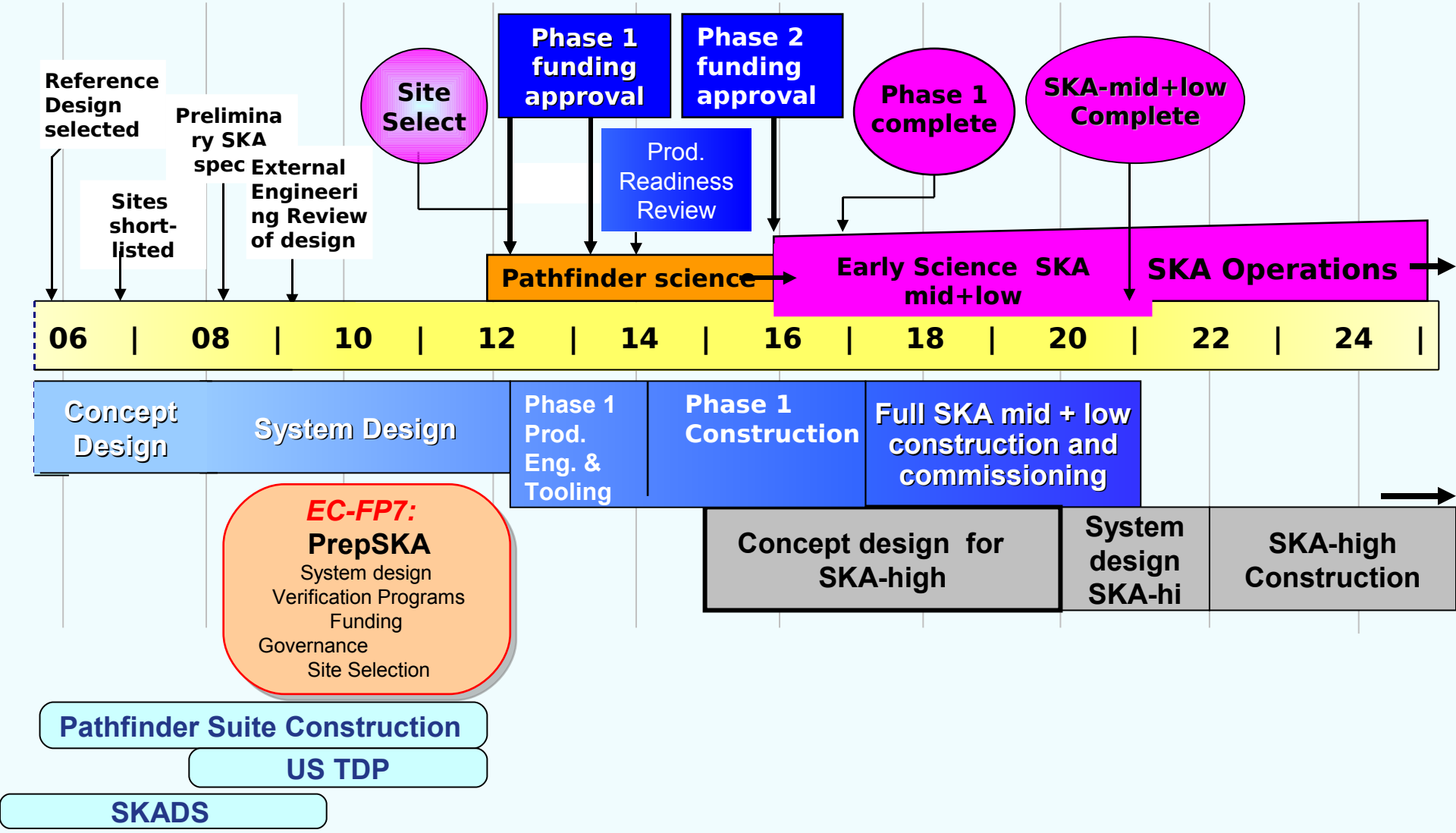
Key dates

2008-2012	**telescope design and cost**
2012	**site selection**
2012-2013	**construction funding approved**
2012-2016	**Phase 1 implementation**
2016 →	**early science with Phase 1**
2017-2021	**construction of full array at low and mid-**

SKA will be built out from the centre

First 15% (phase 1) will have max baselines ~50 km

SKA timeline



PrepSKA; Turning an Artist's Impression into Reality

- **European Commission's 7th Framework Program is funding the Preparatory Phase for the SKA 2008-2012**

  €5.5M EC funding, €17M contributed funding from partners, which taps into the €140M SKA-related R&D around the world

- **Deliverables**

  Produce a deployment plan for the full SKA and a detailed costed system design for Phase 1

  Integrate all of the activities, reports, and outputs of the various working groups to form an SKA implementation plan including a build plan

  → **proposal for construction funding in 2012**

7 work packages

WP1 PrepSKA management

WP2 Costed telescope design

WP3 Further site characterization in Australia and Southern Africa

WP4 Governance

WP5 Procurement and involvement of industry

WP6 Options for funding

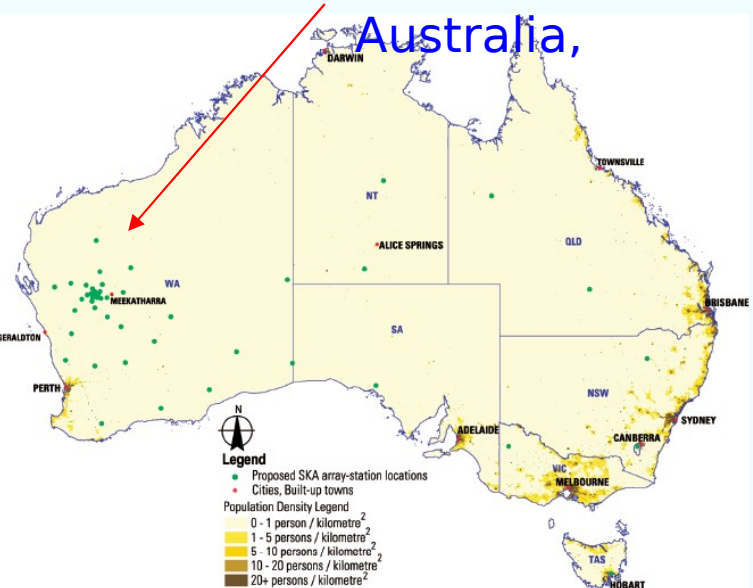
WP7 Impact on broad government priorities

WP2 Coordinated by SKA Project Development Office @ University of Manchester

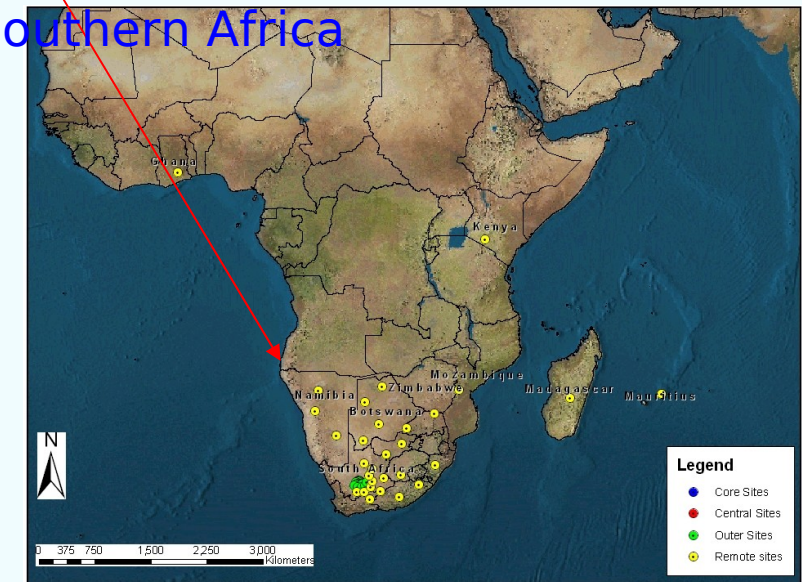
Site selection

- **Physical characteristics required**
  - Very quiet radio frequency environment, particularly for the core region
  - Large physical extent (>3000 km)
  - Low ionospheric turbulence
  - Low troposphere turbulence
- **Not many suitable sites in the world; short list of acceptable sites for final selection in 2012**

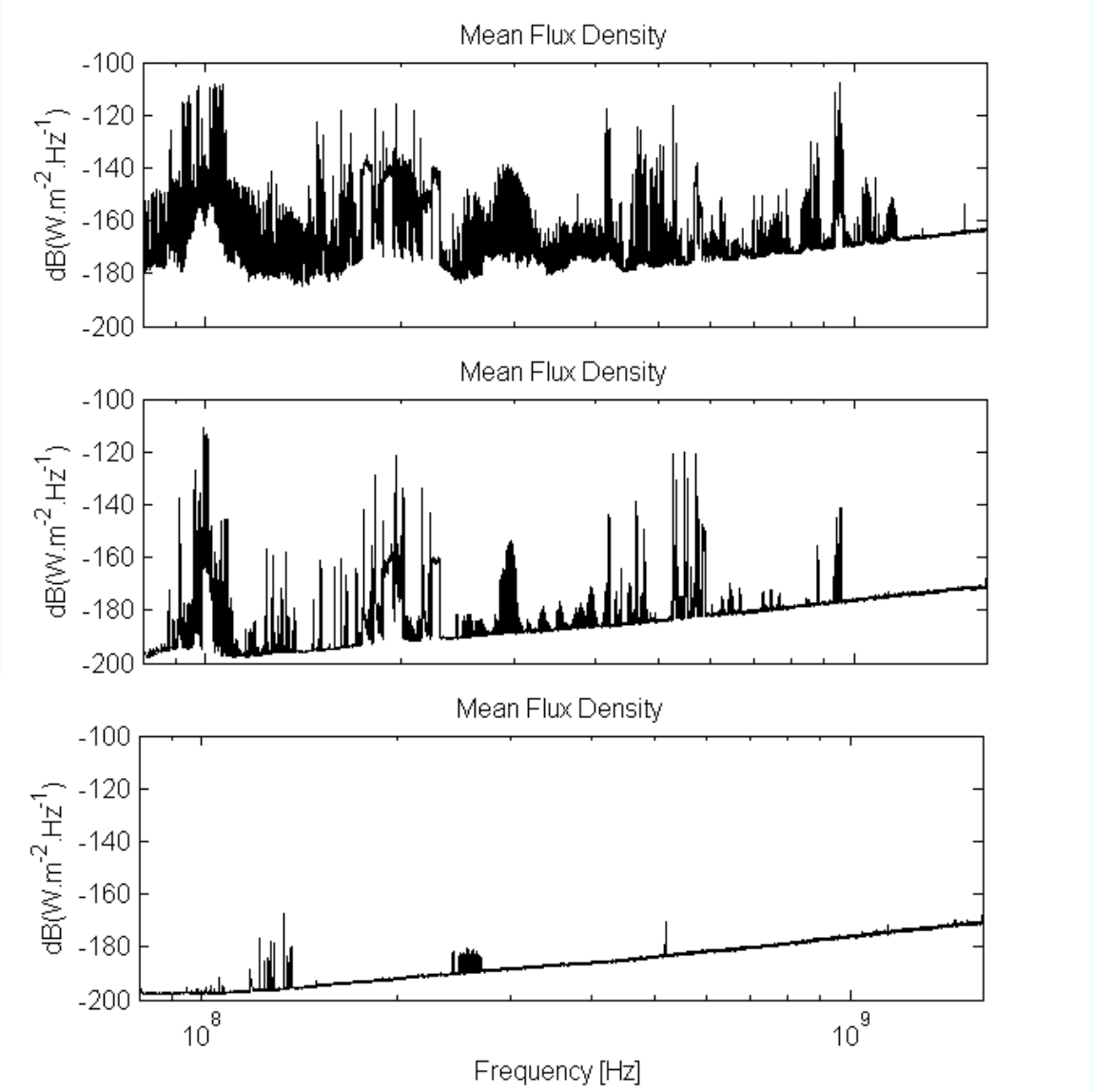
Australia,



Southern Africa



Site selection

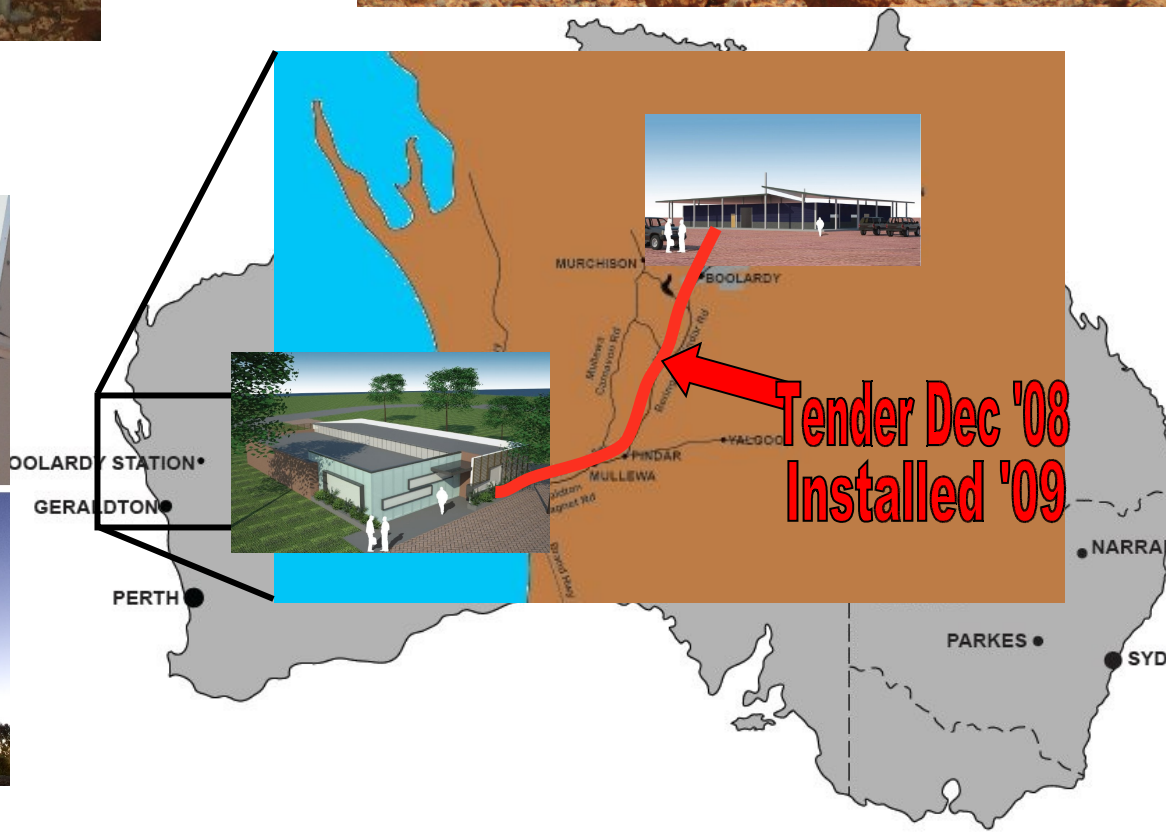


Sydney
population: several million

Narrabri
population: several thousand

Boolardy Station (WA)
population: a few


YOU ARE NOW LEAVING THE
MURCHISON RADIO-ASTRONOMY
OBSERVATORY
THANK YOU FOR BEING RADIO QUIET


MURCHISON
BOOLARDY
BOOLARDY STATION
GERALDTON
PINDAR
MULLEWA
PERTH
PARKES
Tender Dec '08
Installed '09

MeerKAT: Prototype 15 m composite dish

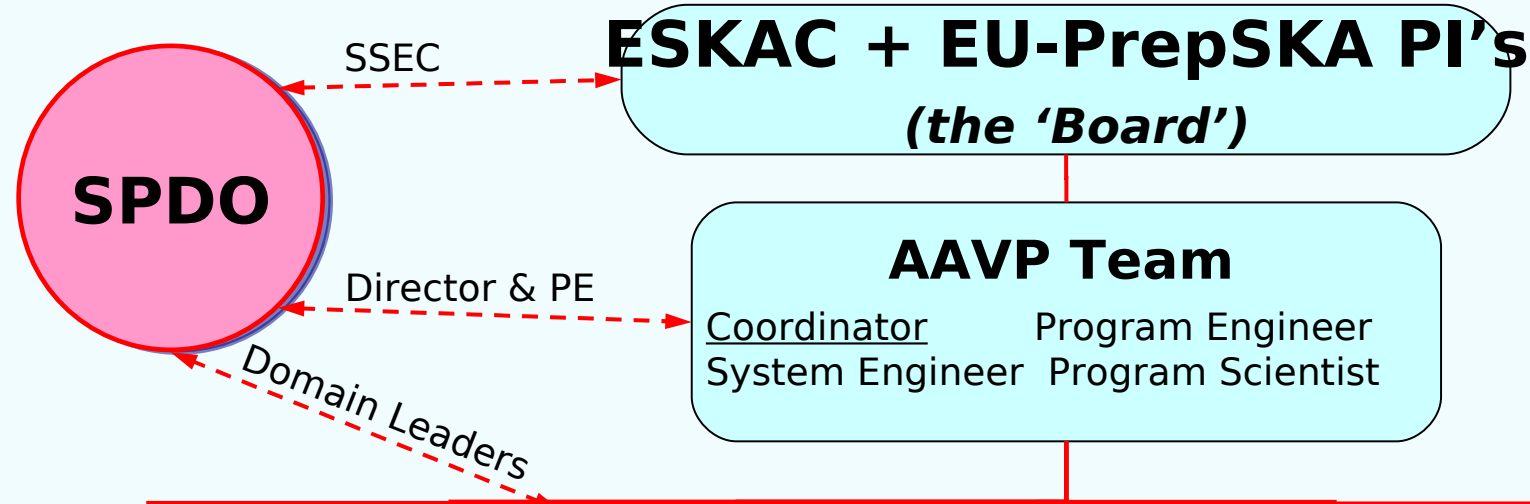
- Fibreglass & foam
- One-piece surface
- f/D = 0.5
- Foundations dug in Nov 2006
- “First light” (L- and Ku-band) July 2007
- Photogrammetry and Ku-band radiometry show rms < 2 mm

Training the next generation for SKA

Medicina 23-29 Sept 2007

- Wide field imaging and calibration
Groningen 2-7 March
- Synergies with the SKA
Bonn 14-18 April 2008
- Deep Field Imaging with SKA
Cambridge 25-29 Aug
- Radioastronomy and the New Instruments
Siguenza 27 Aug – 4 Sept
- Multifield and multibeam science with SKA
Oxford 15-27 March 2009

Possible Organisation Char



AA-Lo

INAF/IRA

Development of the low frequency specific AA components. Most sub-systems will be re-used from AA-hi. Lessons learned from activities in LOFAR and other LF Arrays.

AA-SDS

UK

System design studies with close connection to the requirements to meet the science goals.

Inc. simulations, costing & proc'g requirements.

AA-SEM

Portugal

Provide a site, infrastructure and power for a representative site, including solar power.

Assist with detailed testing of AAs installed.

DAAVS

UK

Build, test & calibrate an all digital AA. On a representative site.

Use 2-PAD & derivatives for ongoing test and development.

A3IV

ASTRON

Build and test astronomically capable AA.

Use EMBRACE & derivatives for ongoing test and development.

AA-Tech

ASTRON

The development programmes for the AA sub-systems.

The technology developed here are used in the demonstrators.

Further information

www.skatelescope.org

FP6: www.skads-eu.org

FP7: www.prepska.org