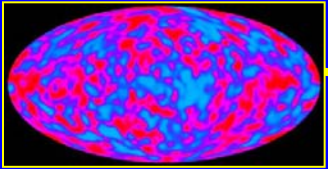
Square Kilometer Array

<www.skatelescope.org>

Astronomy Before the Light

"Primordial soup" – matter and energy

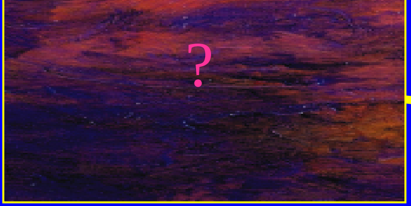


radio

COBE satellite NASA

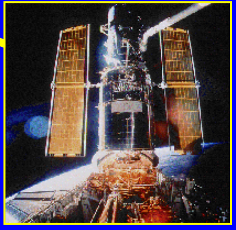
"Dark Ages"

before the stars



Early galaxies- stars light up

light



Hubble Space Telescope NASA / ESA

Radio Astronomy Discoveries

- Non thermal radiation
- Solar radio bursts
- Jupiter radio bursts
- Rotation of Mercury
- Internal heat source in giant planets
- Giant molecular clouds
- Cosmic masers
- Extrasolar planetary system
- Radio Galaxies (black holes)
- Cosmic evolution
- Quasars
- Relativistic jets
- Pulsars (neutron stars)
- Gravitation lensing
- Gravitational radiation
- Cosmic Microwave Background

The SKA

next generation “discovery” telescope in the meter to centimeter wavelength region with

- 100 x sensitivity of EVLA
- large instantaneous field of view
- new modes of operation (multiple simultaneous users)

extremely powerful survey telescope with the capability to follow up individual objects with high angular and time resolution

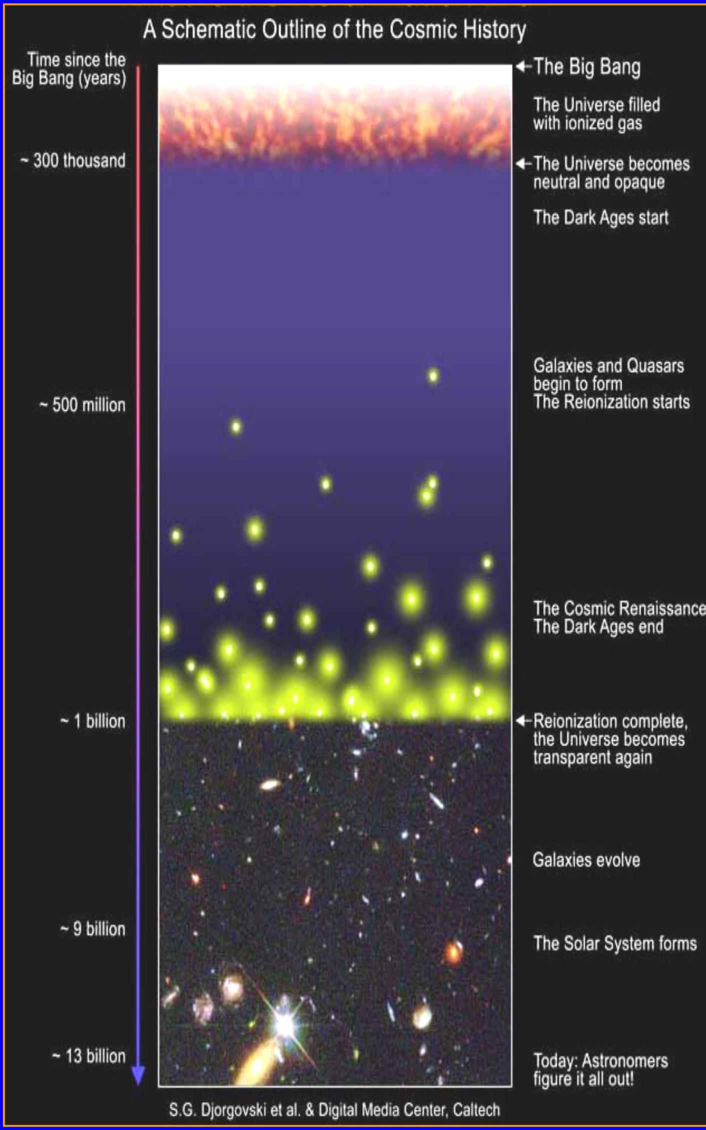
Key Science Projects

- probing the dark ages before the universe lit up
- the evolution of galaxies and large scale structure in the universe
- strong field tests of gravity using pulsars and black holes
- the origin and evolution of cosmic magnetism
- the cradle of life

\+ <u>exploration of the unknown</u>

science case to be published in July 04 (Eds. Carilli and Rawlings)

science requirements on technology identified

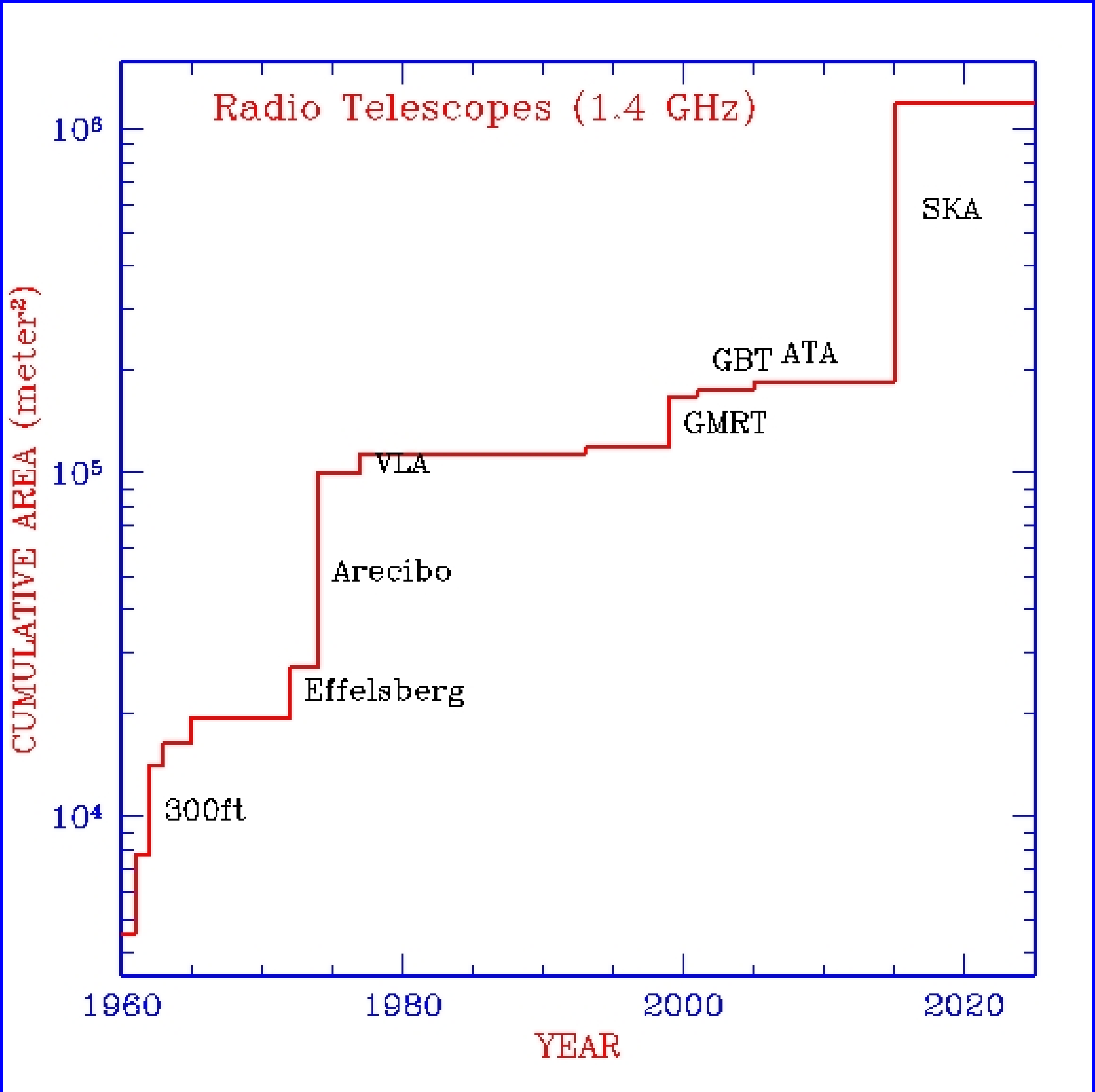


SKA Goal – 100 x improvement in sensitivity over EVLA

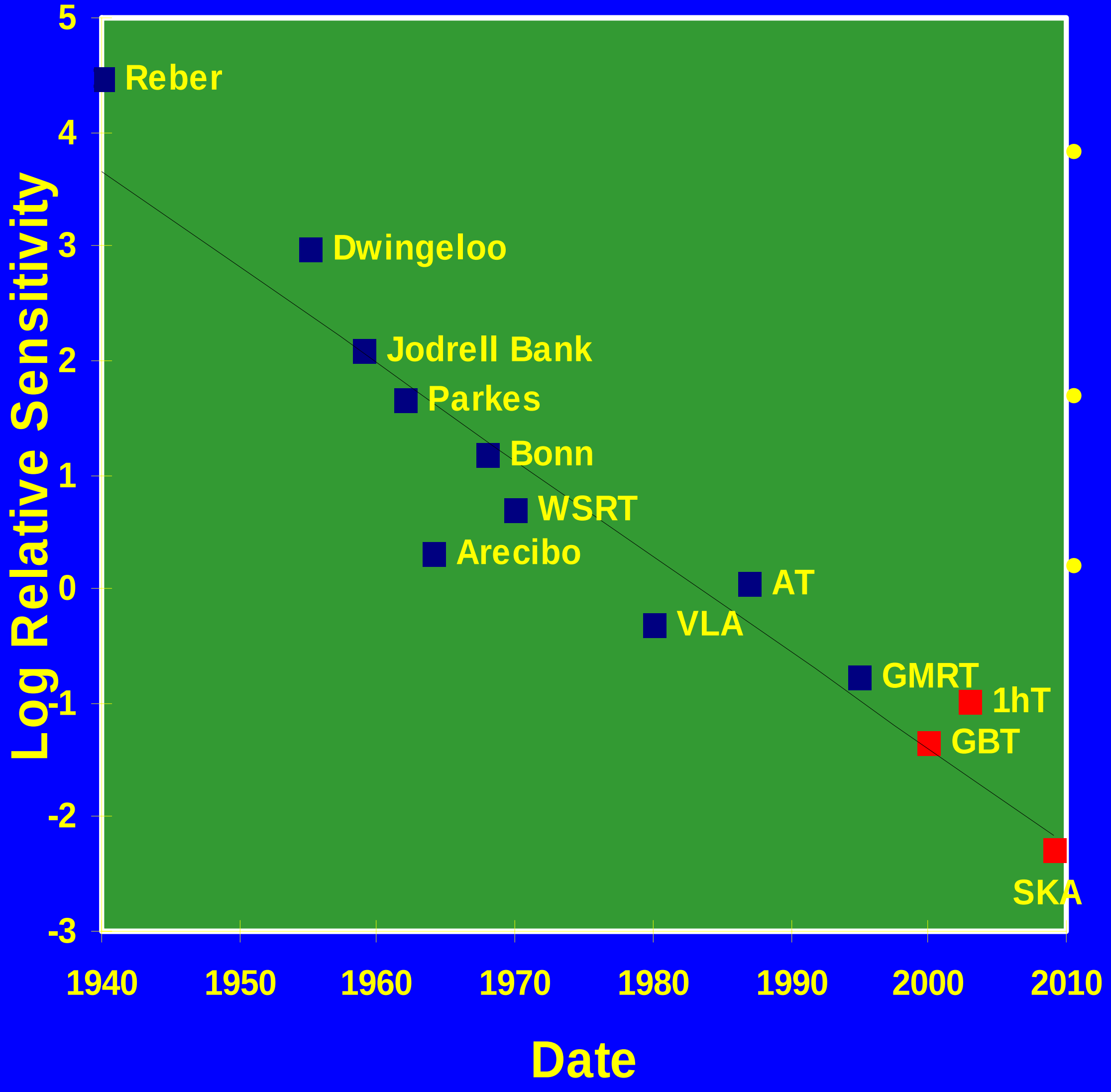
- First epoch of star formation and galaxy formation at z = 1
  - Molecules at z >> 1
- NanoJy continuum surveys
  - 25 nJy rms in 1 hour
  - Normal Galaxies at z = 1
- Spiral galaxies HI at z =1
  - CO at z=5
- Transient radio sources
  - Giant pulses, flares
  - ISS – high resolution observations of pulsars, GRBs
- Radio galaxies, quasars, BH and relativistic beam physics
  - Acceleration near MBHs Magnetic fields
  - Jets, galaxies, clusters, Faraday rotation
- Cosmic (H_2O) masers
  - Geometric distance beyond the local flow
- Stars of all types - thermal
- Solar System
  - Asteroids, comets
- Census of MilkyWay Pulsars
- SETI

Today's hot new issues are tomorrow's old issues.

The excitement of the SKA will be not in the old questions it will answer but in the new questions it will raise!


Radio Telescopes (1.4 GHz)
CUMULATIVE AREA (meter^2)
10^6
10^5
10^4
1960
1980
2000
2020
YEAR
300ft
Effelsberg
Arecibo
VLA
GMRT
GBT
ATA
SKA

Radio Telescope Sensitivity



- Exponential increase in sensitivity x 10^5 since 1940 !
- 3 year doubling time for sensitivity
- No technical reason not to continue this growth

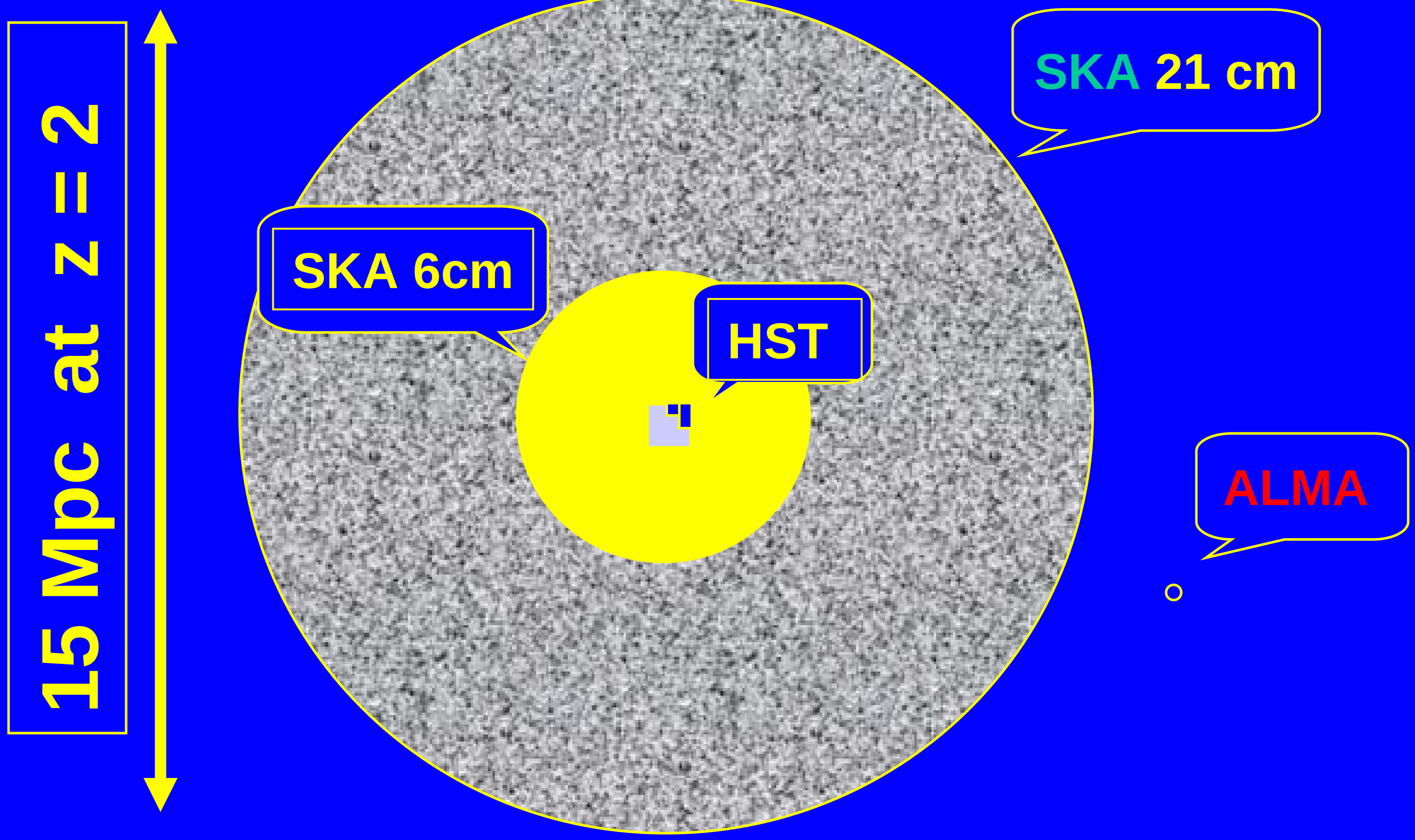
Key Technical Specifications

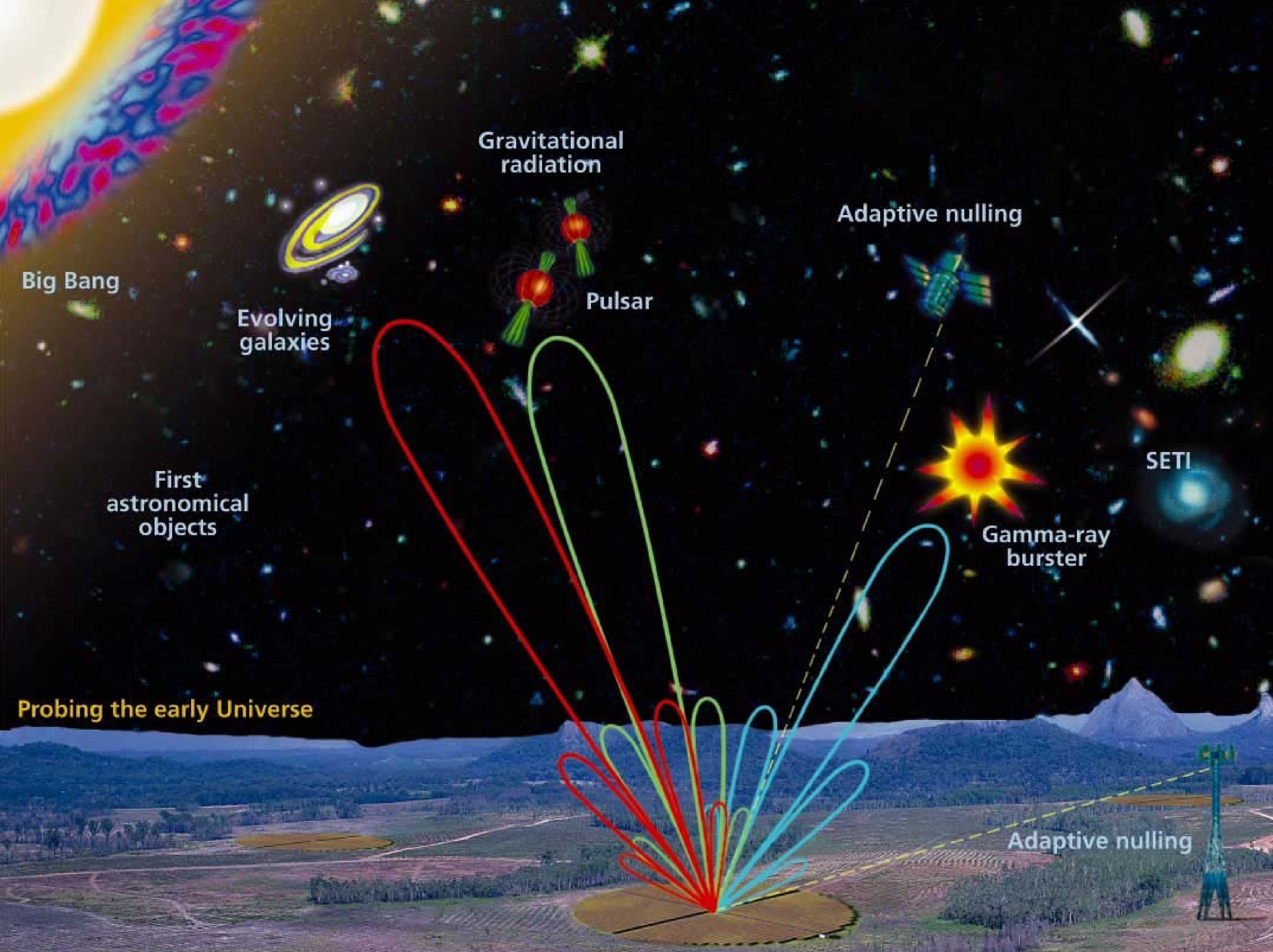
- **collecting area** of order 1 million square meters
- **frequency range** 100 MHz – 25 GHz
- **large instantaneous field of view** 1 sq. deg. at 1.4 GHz
  (goal 50 sq.deg.)
- **configuration**
  - 20% of total collecting area within 1 km diameter,
  - 50% of total collecting area within 5 km diameter,
  - 75% of total collecting area within 150 km diameter,
  - 100% of total collecting area within 3000 km from array core.

SKA design goals

- Aeff/Tsys: 2 x 10^4 m^2/K
- Angular resolution: 0.1 arcsec or better @ 1.4 GHz
- Frequency range 100 MHz - 30 GHz
- Imaging Field of View: 1 square deg. @ 1.4 GHz
- Number of instantaneous pencil beams: 100
- Number of pixels: 10^8
- Clean beam dynamic range: 10^{6-7}
- Surface brightness: 1K @ 0.1 arcsec (continuum)
- Instantaneous bandwidth: 0.5 + f/5 GHz
- Minimum number of spectral channels: 10^4
- Number of widely spaced, simultaneous frequency bands: 2
- Polarisation purity: -40 dB

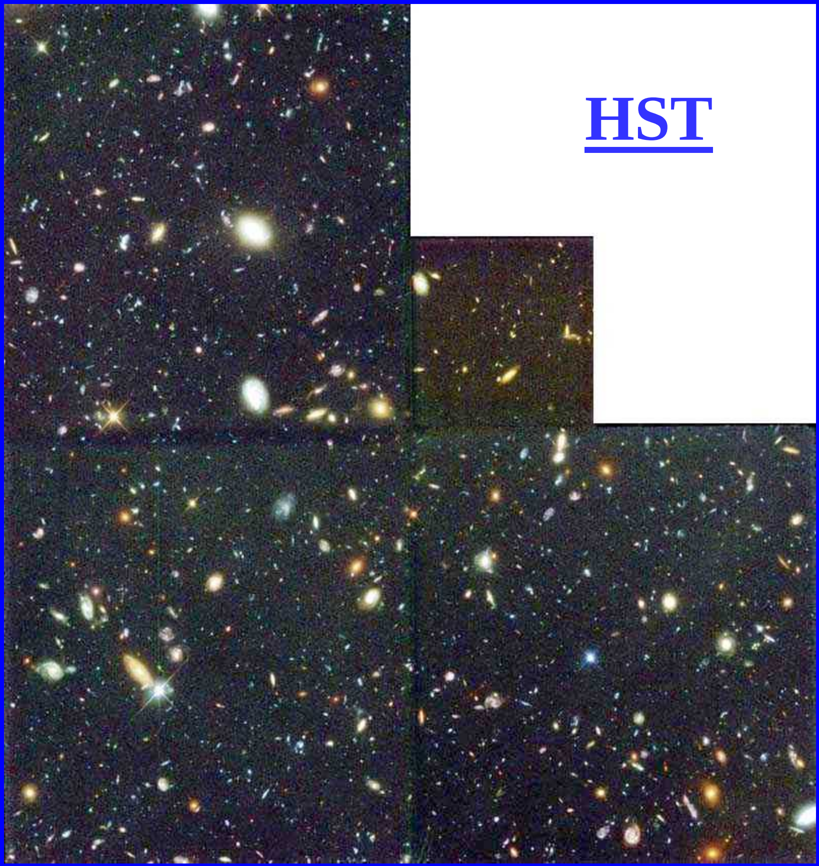
1 deg^2 (minimum) field-of-view for surveys and transient events

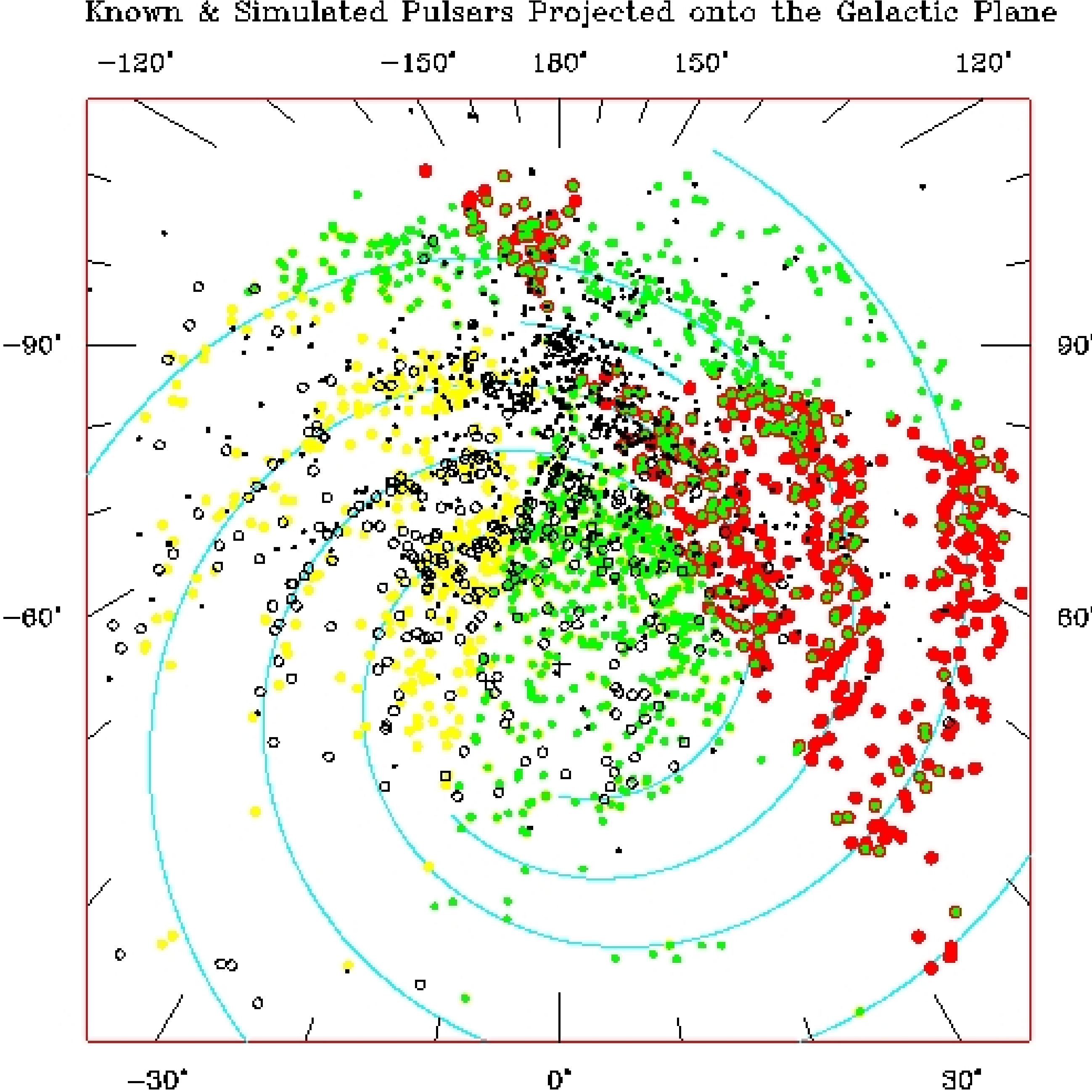




Big Bang
Evolving galaxies
Gravitational radiation
Pulsar
Adaptive nulling
First astronomical objects
Gamma-ray burster
SETI
Probing the early Universe
Adaptive nulling

Future Sensitivity

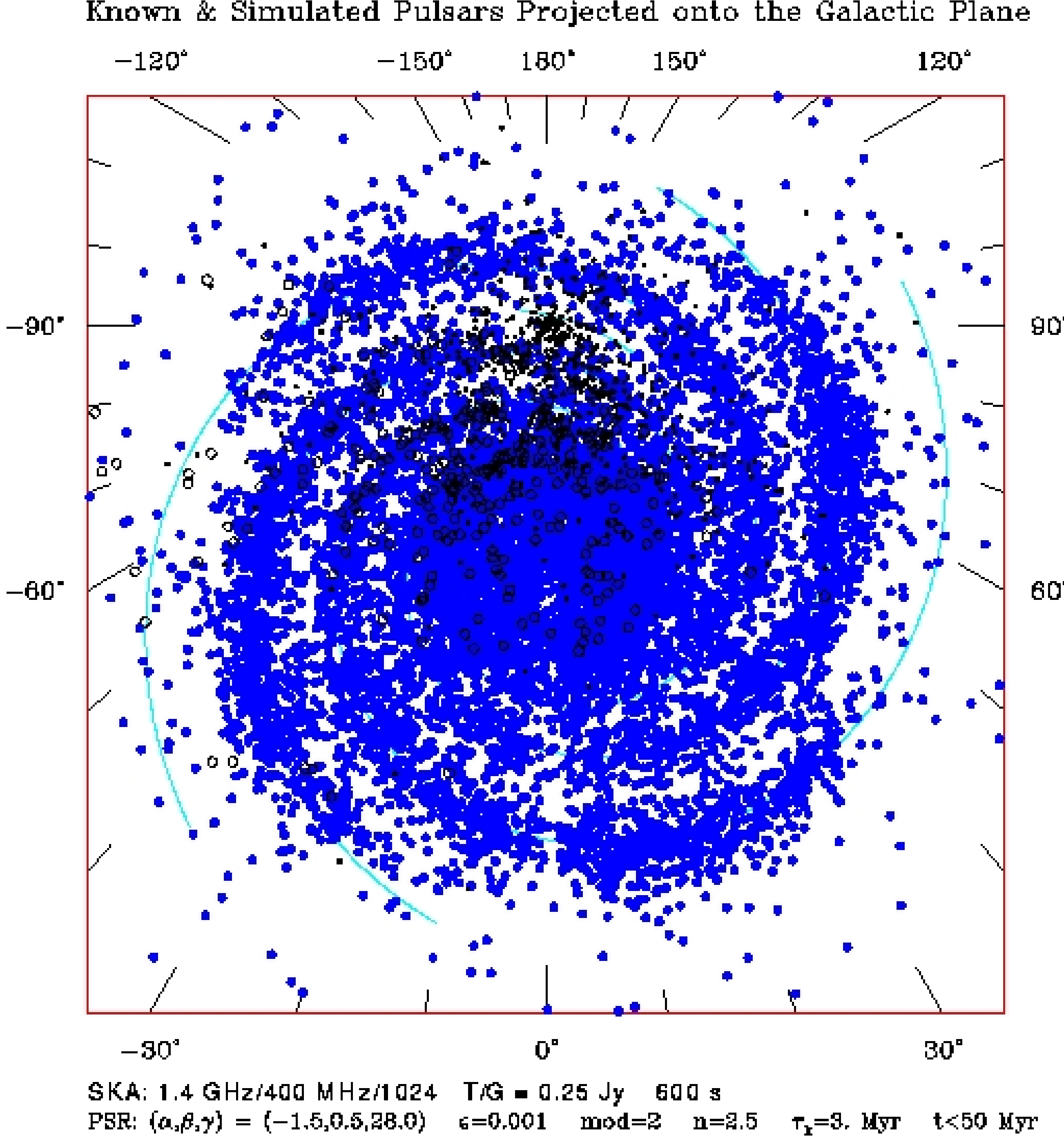




Surveys with Parkes, Arecibo & GBT.

Simulated & actual pulsars shown

Yield ~ 1000 pulsars in ALFA survey



SKA pulsar survey

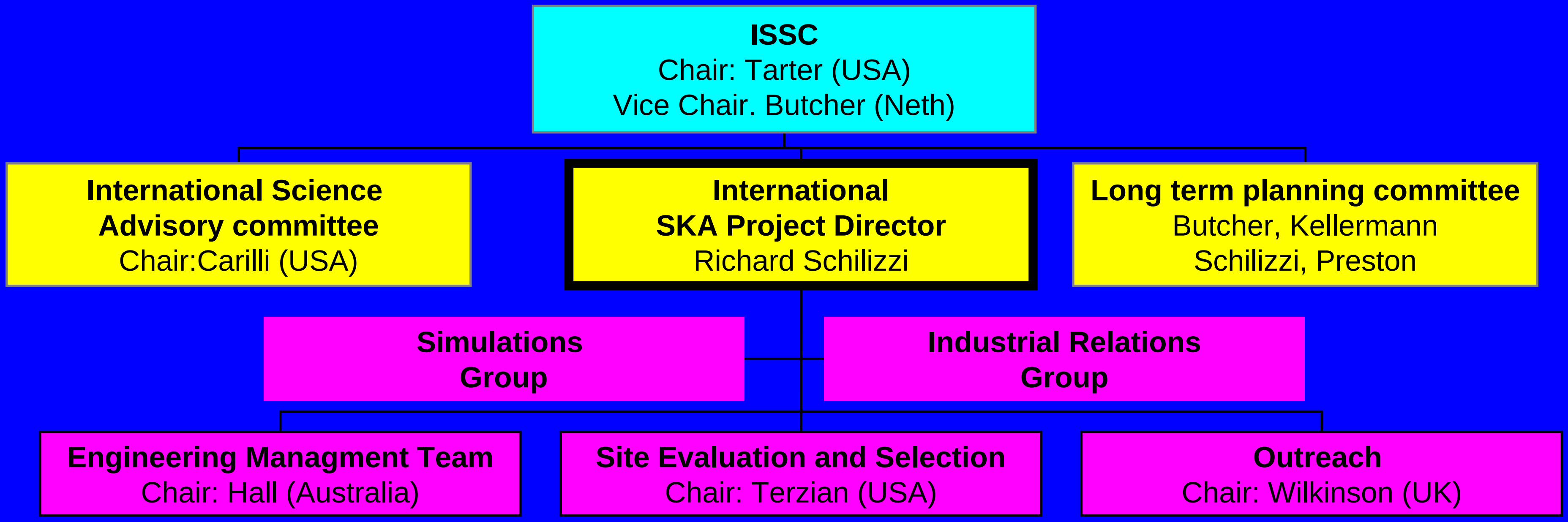
600 s per beam

~10^4 psr's

SKA History

- First Discussions: 1991
- 1994 URSI---IAU Large Radio Telescope WG formed
- 1997 S&T Workshop, Leiden, Netherlands
- 1998 S&T Workshop, Calgary, Alberta, Canada
- 1998 S&T Workshop, Green Bank, WV
- 1999 S&T Workshops, Leiden & Dwingeloo, Netherlands
- 2000 S&T Workshop, Manchester, UK
- **2000 ISSC formed, MOU signed at IAU GA**
- 2001 S&T Workshop, Berkeley, CA, USA
- 2002 S&T Workshops, Bologna, Italy, Groningen, Netherlands
- 2003 S&T Workshop, Geraldton, WA, Australia
- 2004 S&T Workshop, Cape Town, South Africa

Current SKA Management Structure



International SKA Steering Committee (ISSC)

19 members representing 11 countries
Chair: J. Tarter (SETI Institute)

- –6 European (UK, Germany, Netherlands, Italy)
- –6 United States (Tarter, Welch, Terzian, Kellermann, Preston, Cordes)
- –2 Canada
- –2 Australia
- –2 Asia (China, India)
- –1 At-large member (Burke)
- –Observers from Japan, South Africa, Russia

SKA International Timeline

- 2002.5 Initial Concept Whitepapers
- 2003.5 Updated Concept Whitepapers
- 2003.5 Site Proposals
- 2004.5 Updated Concept and Site Whitepapers
- 2005.5 Final Site proposals
  Concept downselect
- 2006.1 Site Selection
- 2007 Concept selection (hybrid design?)
- 2009 Preparations for construction proposals
- 2015? Complete construction

How to build the SKA

- **Brute force** – Replace all EVLA antennas (27 VLA + 8 NMA + 10 VLBA) with 45 GBTs. Use EVLA infrastructure - fiber, correlator, receivers, computers, software: *Cost about \$ 5 x 10^9*
- **Be Clever!**

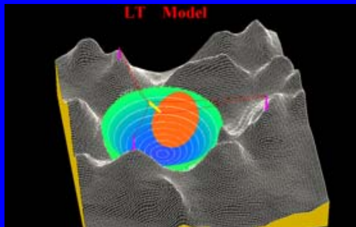
Current activity around the world

1. Larger antenna elements
   - –Multiple Arecibos in KARST formations (FAST, China)
   - –Large adaptive reflector (CLAR, Canada)
   - –Array of cylindrical reflectors (SKAMP, Australia)

2. Smaller antenna elements
   - –Array of small dishes (ATA, DSN, USA)
   - –Planar phased array (THEA, SAMBA, BEST, Europe)
   - –Array of Luneburg lenses (Australia)
   - –Array of dipoles (LOFAR=low freq SKA, NL/ US)

We could build the SKA now!

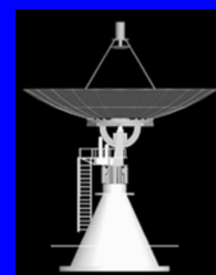
Current Concepts



China KARST

Canadian aerostat

US Large N

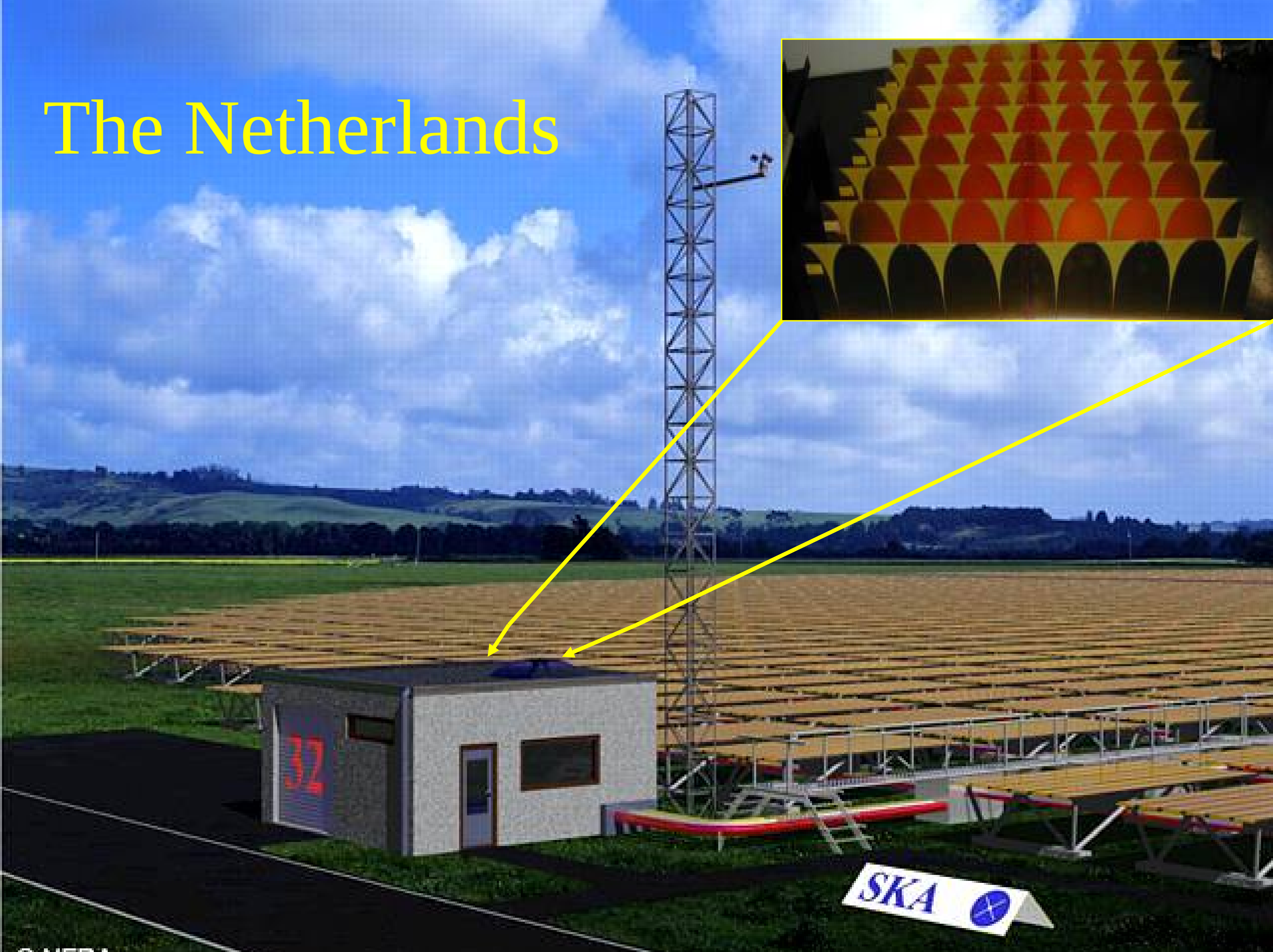


Antenna designs: India, US.

Australia:
Luneburg Lenses and Cylinders

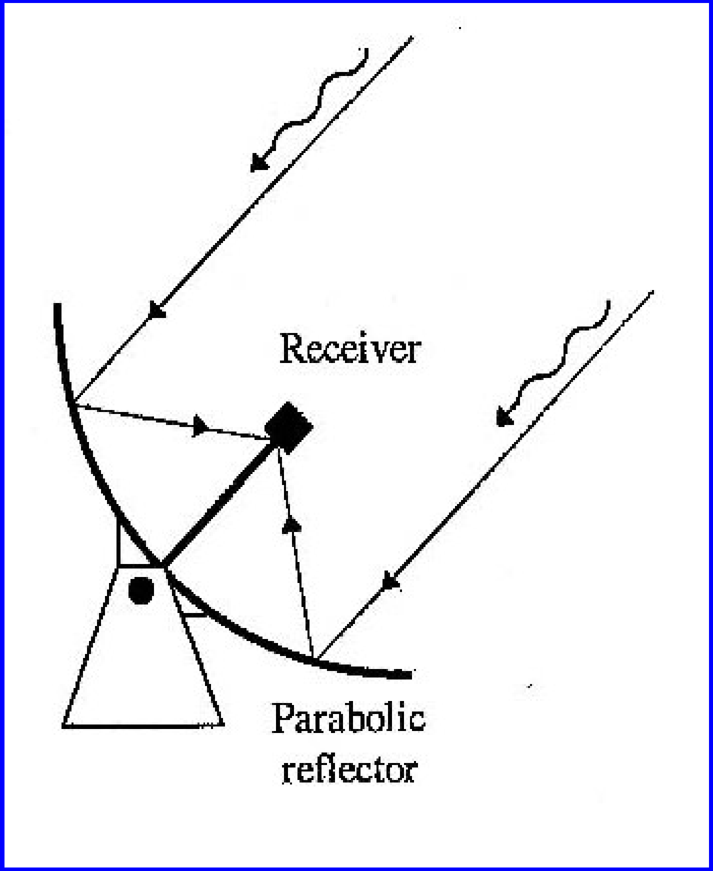
Dutch Fixed
Planar Arrays

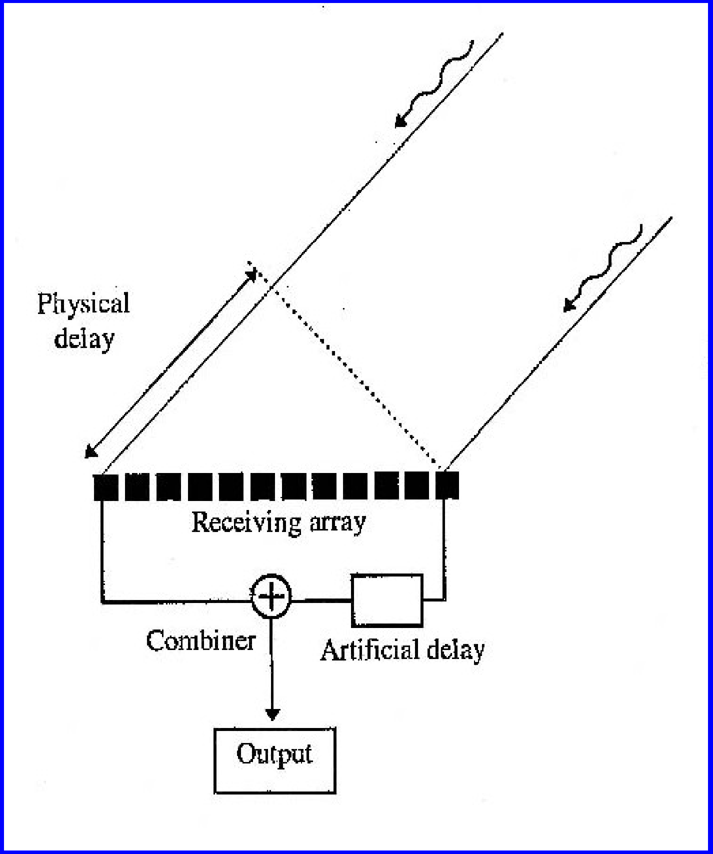
The Netherlands

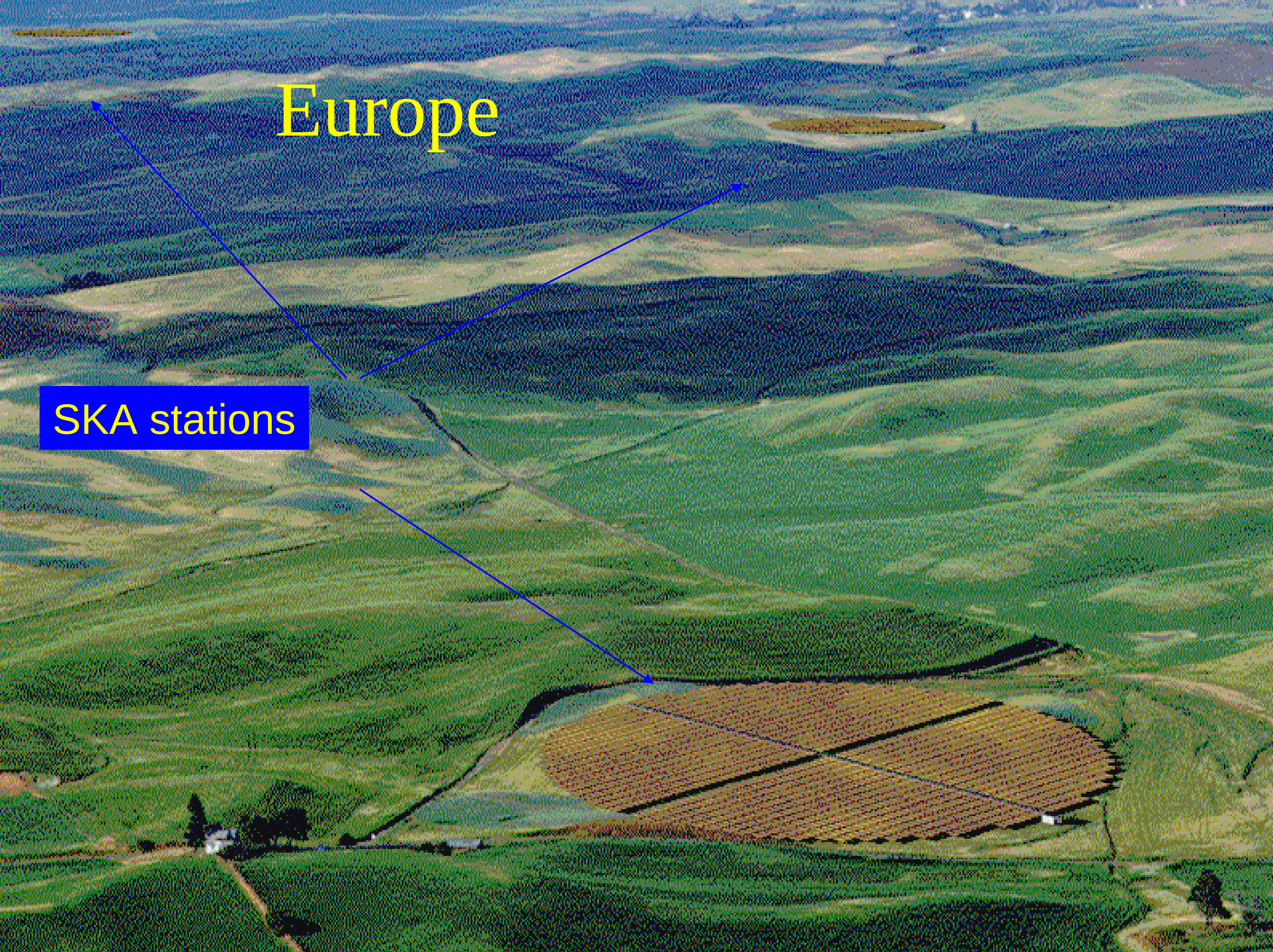


Phased array concept

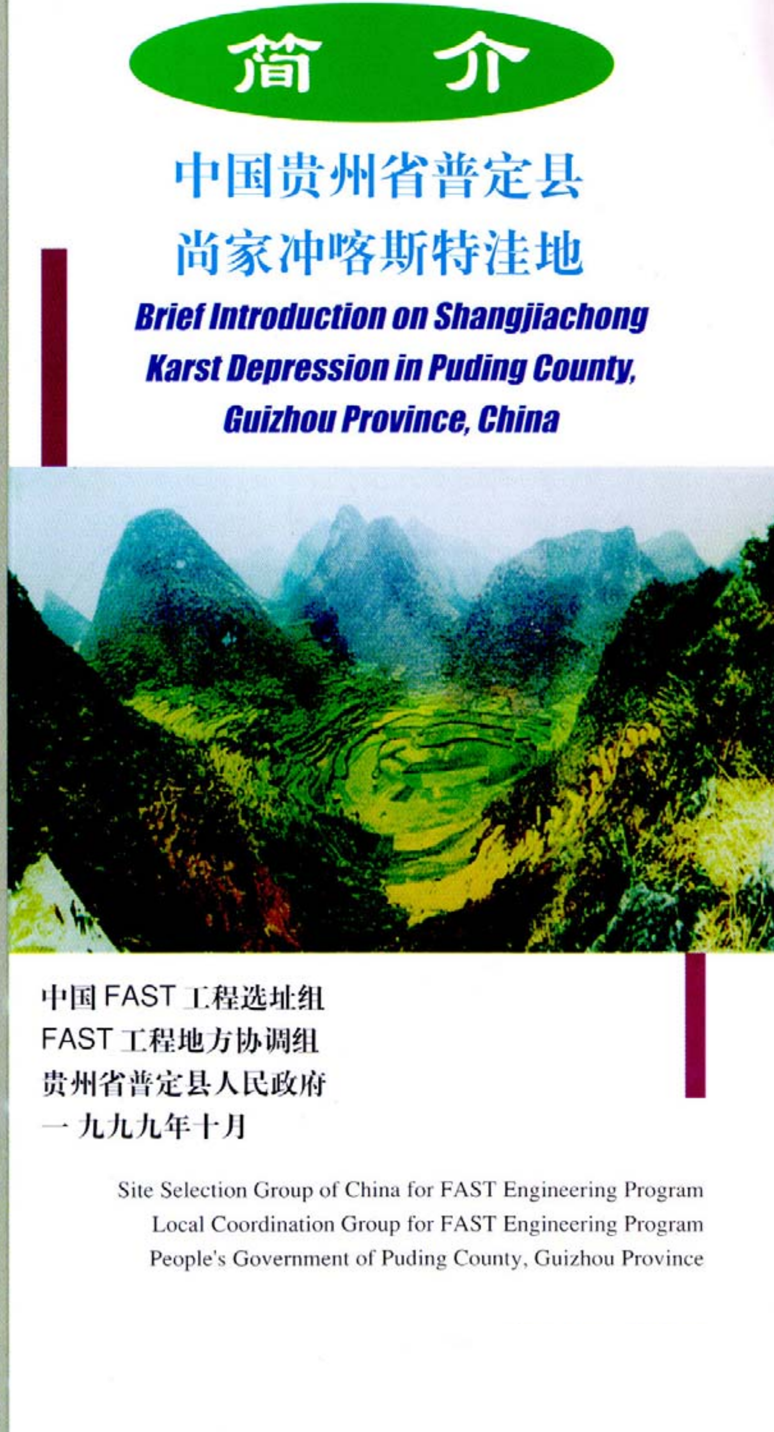
Basic idea: replace mechanical pointing & beam forming by electronic means






Europe
SKA stations

NxArecibo

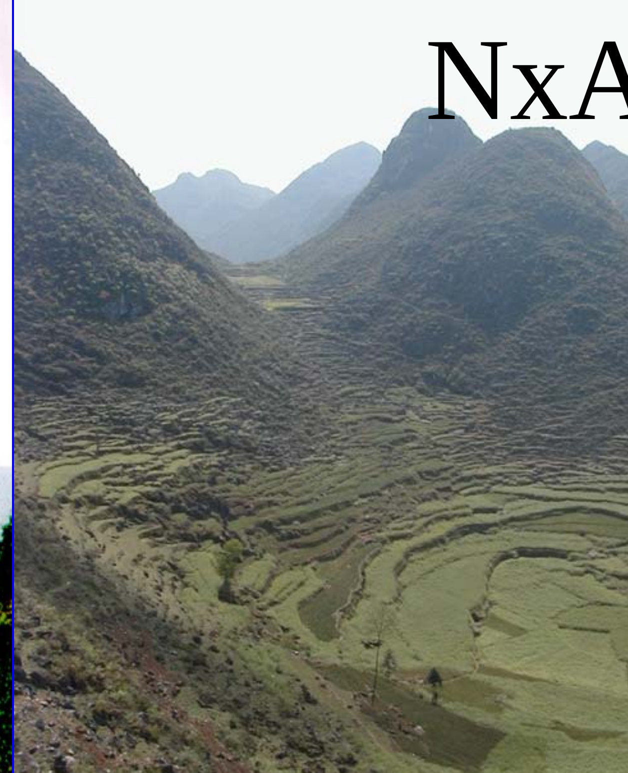

简 介

中国贵州省普定县
尚家冲喀斯特洼地

Brief Introduction on Shangjiachong Karst Depression in Puding County, Guizhou Province, China

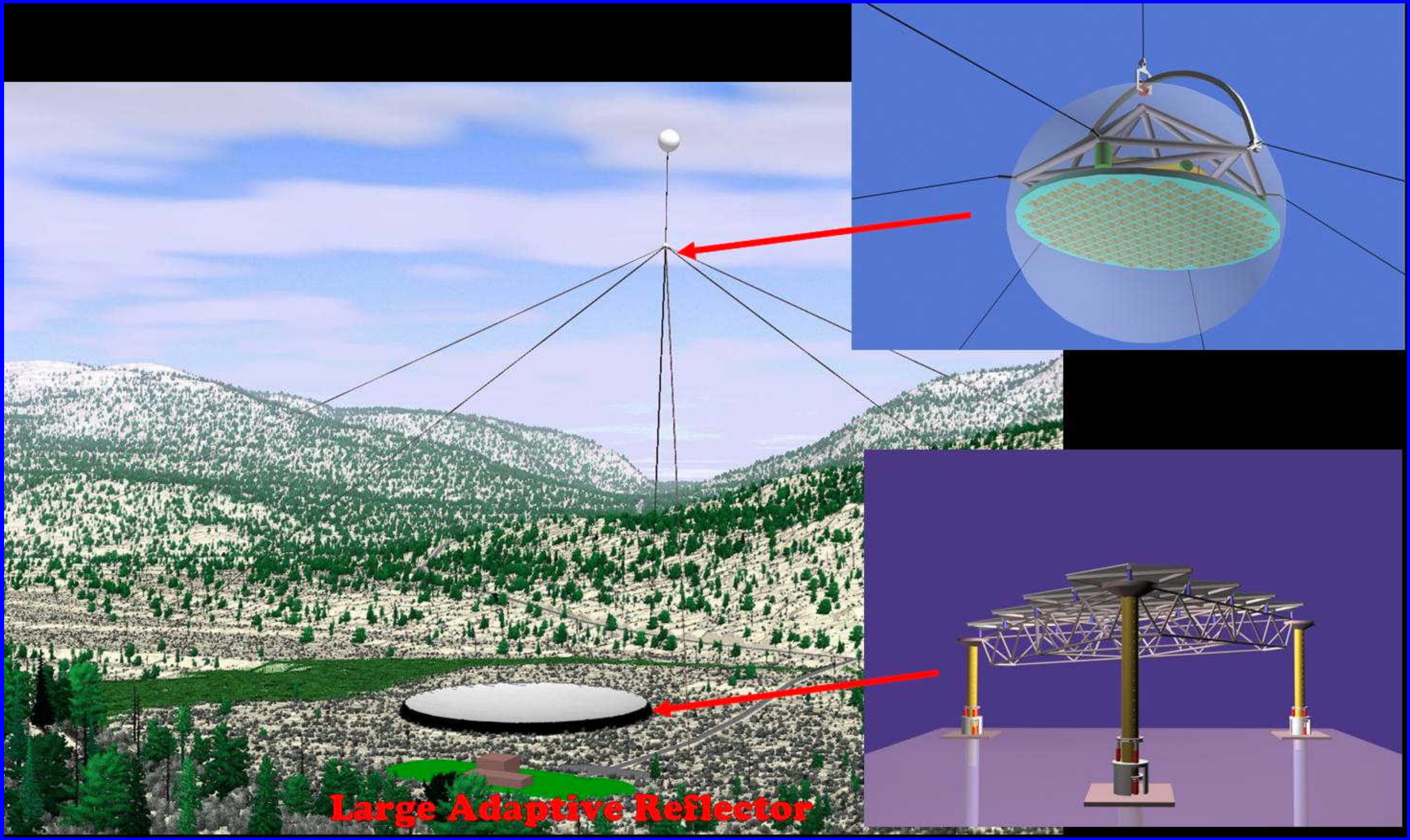
中国 FAST 工程选址组
FAST 工程地方协调组
贵州省普定县人民政府
一九九九年十月

Site Selection Group of China for FAST Engineering Program
Local Coordination Group for FAST Engineering Program
People's Government of Puding County, Guizhou Province



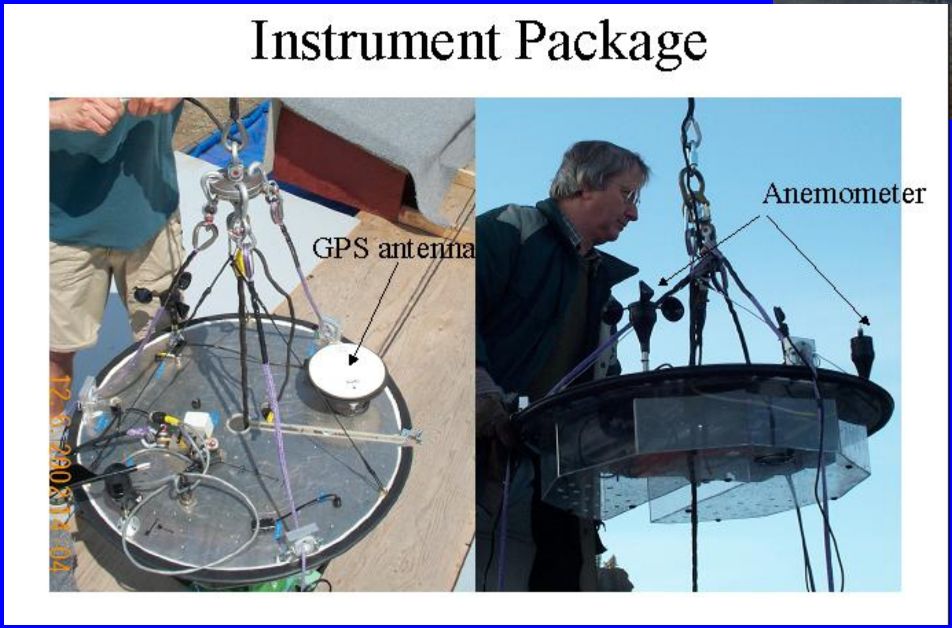
Karst region for array of large Arecibo-like Telescopes

D > 200 m



- 150-200m diameter stations
- large F/D
- focal platform supported by aerostat
- almost flat panels
- 150 MHz to 22 GHz
- DRAO, U Calgary

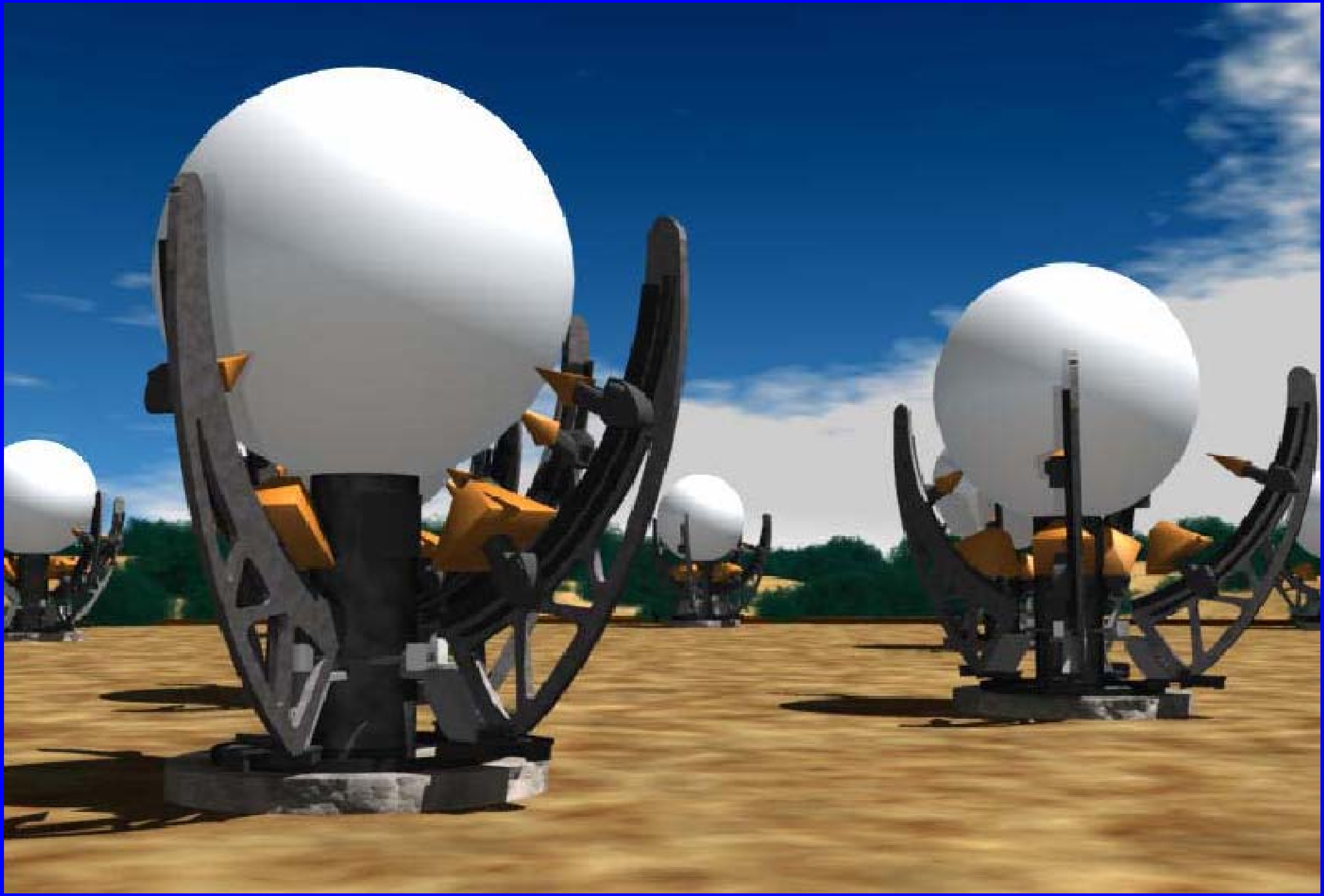
LAR Prototyping



- Focal Plane Array package covering 0.7-1.4 GHz
- RF Feed design
- Beam forming
- Reflector actuators

Australia

Multiple Feeds And Beams



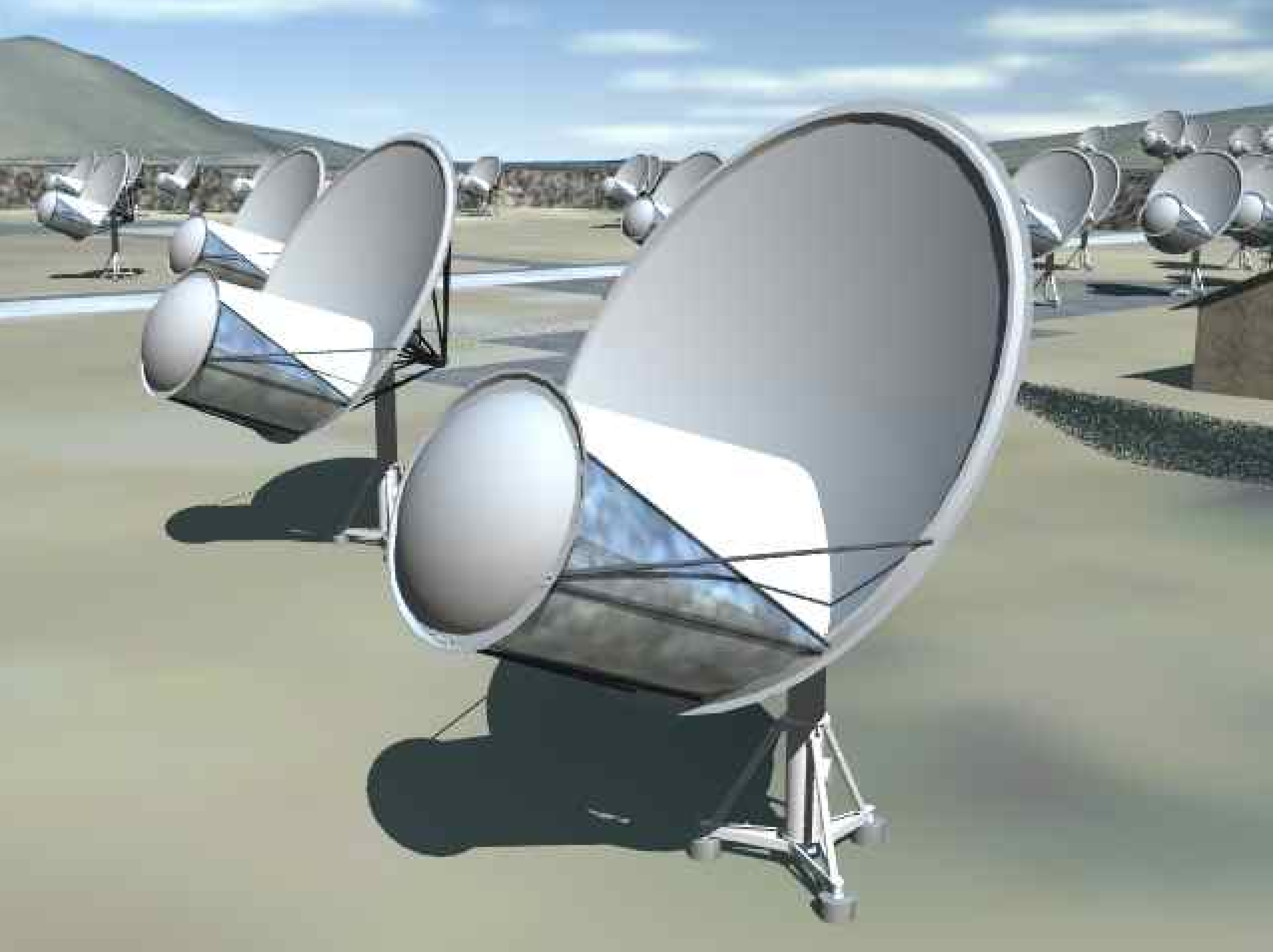
U.S. Consortium Concept Synthesis Array

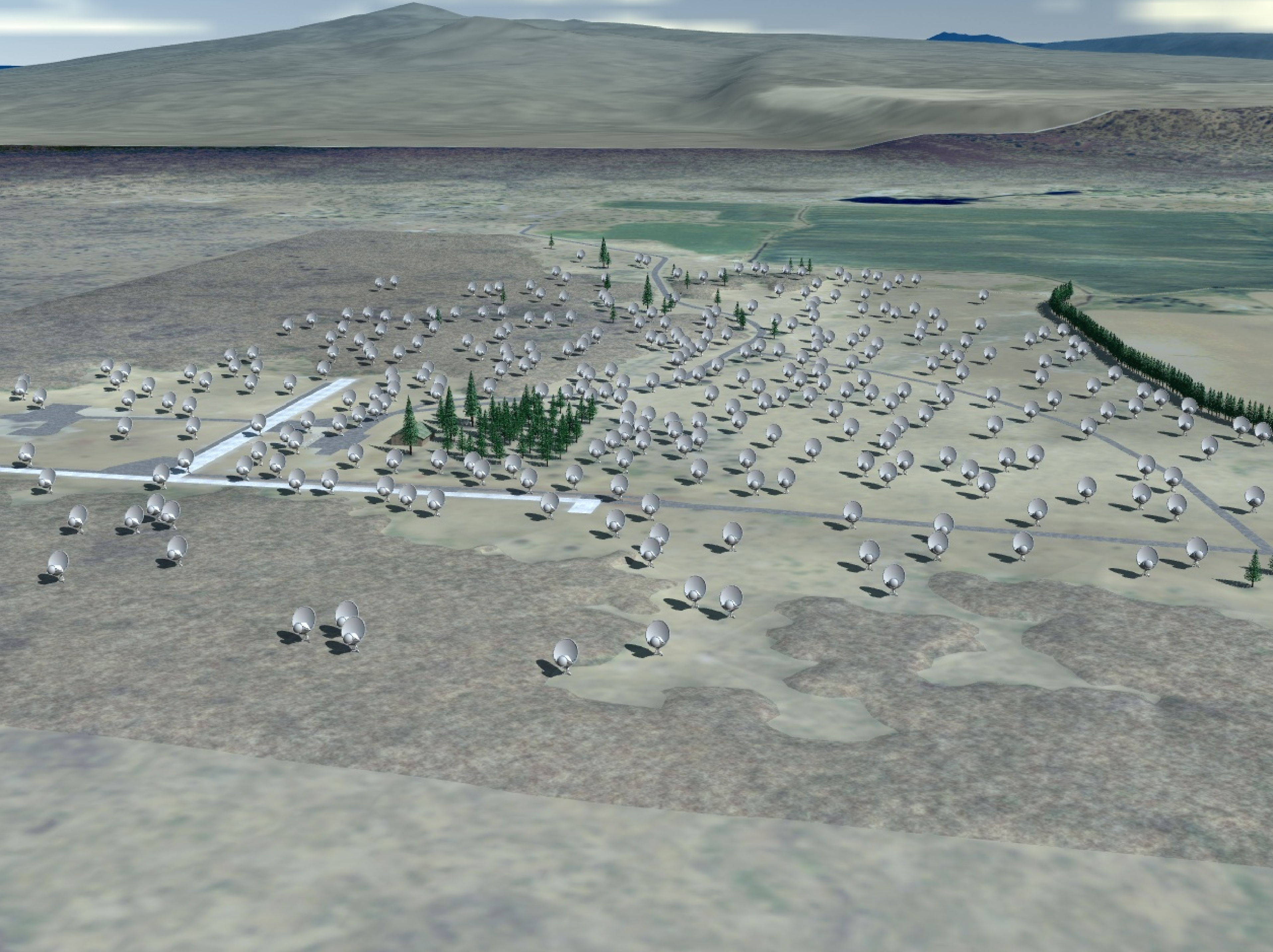
Large N/Small D

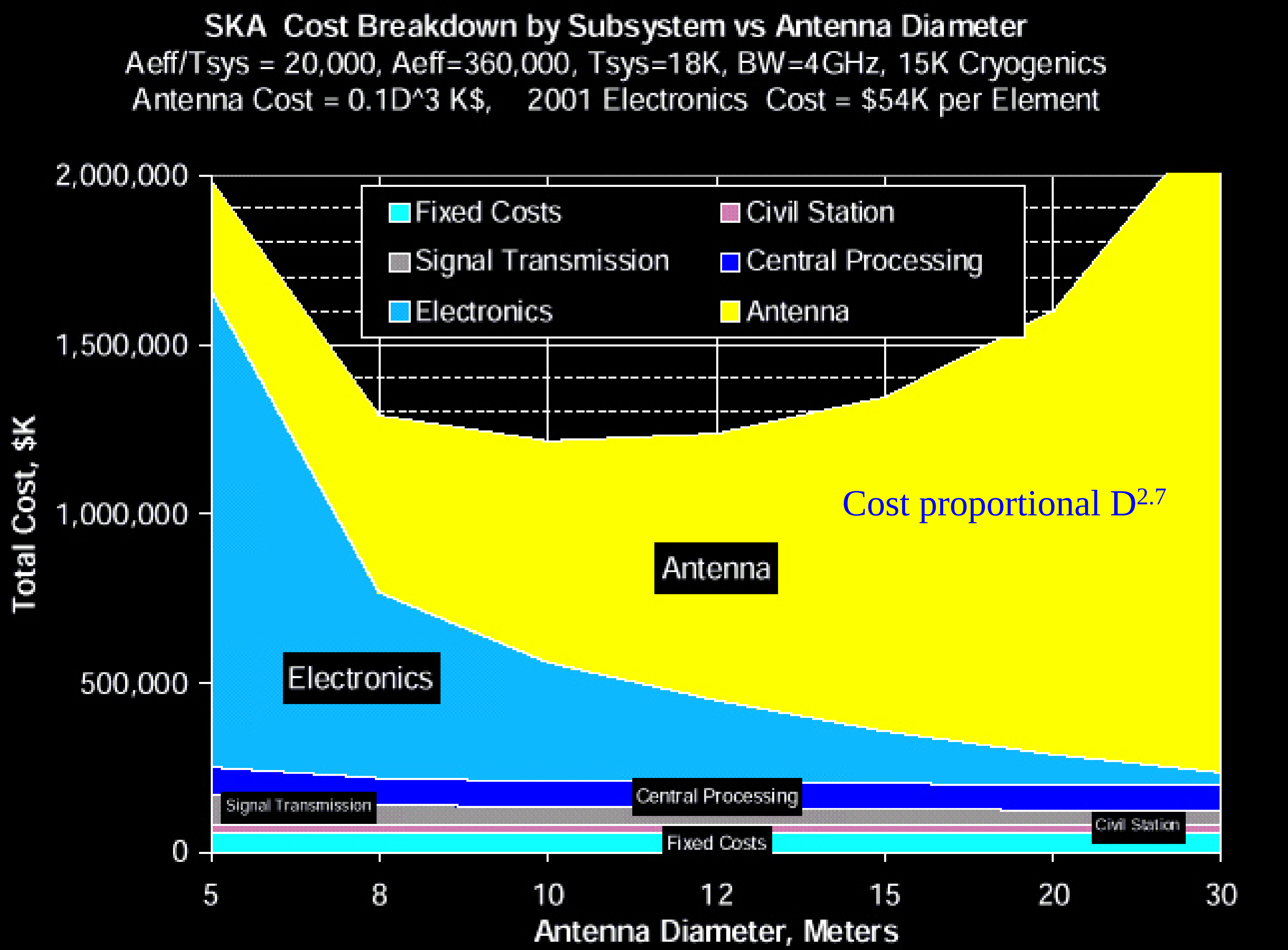
Why parabolic dishes?
- experience
- sky coverage
- frequency coverage

Why large N?
- collecting area
- dynamic range
- baseline diversity
- snapshot mode
- self-calibration
- RFI excision

Why small D?
- field-of-view
- minimizes cost






SKA Cost Breakdown by Subsystem vs Antenna Diameter
Aeff/Tsys = 20,000, Aeff=360,000, Tsys=18K, BW=4GHz, 15K Cryogenics
Antenna Cost = 0.1D^3 K$, 2001 Electronics Cost = $54K per Element
Fixed Costs
Civil Station
Signal Transmission
Central Processing
Electronics
Antenna
Cost proportional D2.7
Antenna
Electronics
Signal Transmission
Central Processing
Civil Station
Fixed Costs
2,000,000
1,500,000
1,000,000
500,000
0
Total Cost, $K
5
8
10
12
15
20
30
Antenna Diameter, Meters

SKA Science Compliance Matrix (from the ISAC as of Sept. 2003)

Level 1 Science	*Strawman*	*KARST*	*TILES*	*PRELOADED*	*LENSES*	*CYLINDERS*	*LNSD*	*LAR*
1: Galactic HI	YES	MAYBE	YES	YES	YES	YES	YES	YES
1: Galactic NT+B	YES	MAYBE	NO	YES	YES	YES	YES	YES
2: Transients	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	YES	YES	YES
2: Pulsars	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	YES	YES	YES
2: SETI	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	YES	YES	YES
3: EOR	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE
4: HI surveys / LSS	YES	MAYBE	YES	YES	YES	YES	YES	YES
4: Continuum surveys	YES	MAYBE	MAYBE	YES	YES	YES	YES	YES
4: CO surveys	YES	MAYBE	NO	MAYBE	MAYBE	YES	YES	YES
5: Hi-z AGN	YES	MAYBE	YES	YES	YES	YES	YES	YES
5: Inner AGN	MAYBE	NO	MAYBE	MAYBE	MAYBE	YES	YES	MAYBE
6: Protoplanetary systems	MAYBE	NO	NO	MAYBE	MAYBE	MAYBE	YES	YES
7: CMEs	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE
7: SS bodies	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	MAYBE	YES	YES
8: IGM non thermal	YES	MAYBE	MAYBE	YES	YES	YES	YES	YES
8: IGM thermal	MAYBE	NO	NO	MAYBE	MAYBE	YES	YES	YES
9: Spacecraft Tracking	MAYBE	MAYBE	NO	MAYBE	MAYBE	MAYBE	YES	MAYBE
9: Geodesy	MAYBE	NO	NO	MAYBE	MAYBE	YES	YES	YES

Notes: Graded into five bins of increasing compliance: (1) NO (red); (2) MAYBE (pink); (3) MAYBE (dark blue); (4) YES (light blue); (5) YES (yellow).

Selection criteria for design concept

- Captures significant fraction of the science in the Key Science Projects
- Demonstrated engineering feasibility and compatibility with site choice
- Maintainable at a reasonable cost
- Upgradable
- Within the nominal cost envelope of 1B Euro/$

Hybrid space

	AA	CYL	KAR	LAR	LNSD	LL	PPD
AA							
CYL							
KAR							
LAR				★			
LNSD	★	★					
LL	★	★					
PPD							

Where will the SKA be built?

- Northern (infrastructure) vs Southern (Galactic Center) hemisphere
- RFI environment
- Troposphere stability (high desert site)
- Political issues – who has the money
- Preliminary proposals
  - U.S., Australia, South Africa, Argentina, Brazil, China
- Decision - 2006

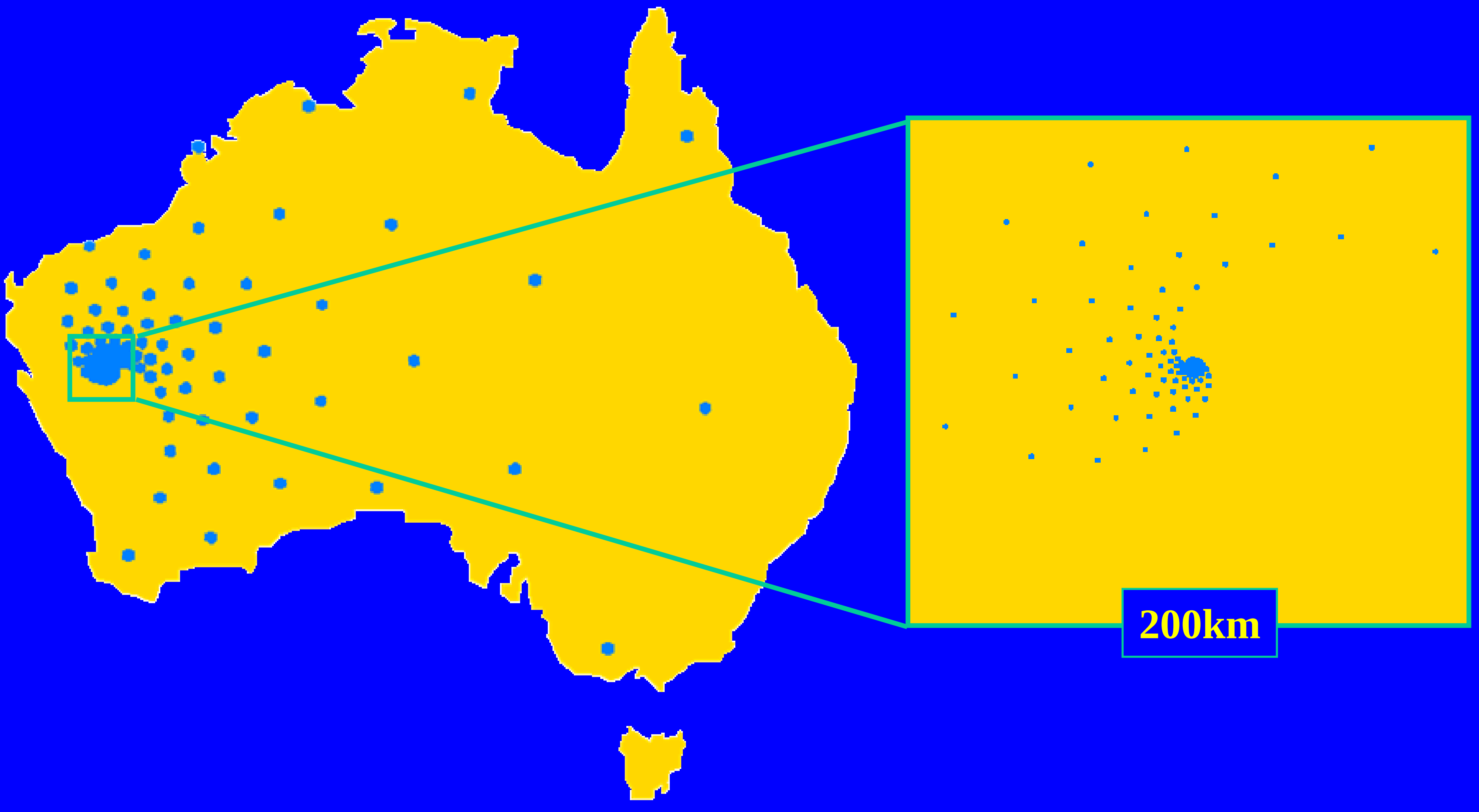
Site

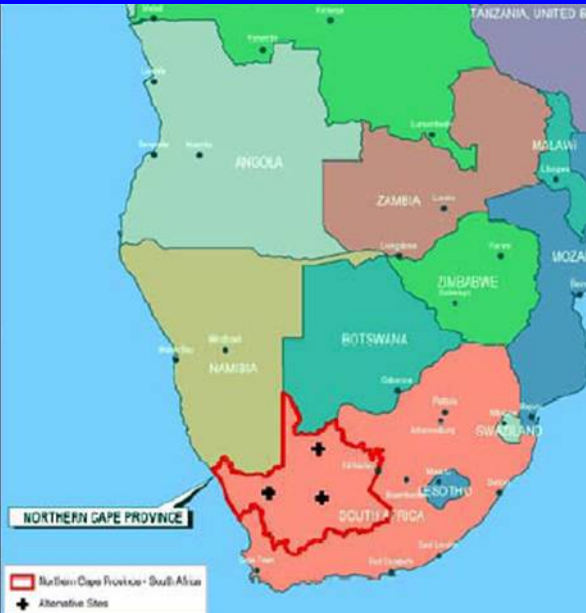
- Initial site analyses submitted by Australia, China, South Africa, and USA in May 2003
- Additional information supplied in December 2003
- Initial site analyses by Argentina and Brazil submitted 31 March 2004
- Formal Request for Proposals to be issued in July 2004, due 31 May 2005
- RFI testing at candidate sites in 2004-5, calibrated by ASTRON team under contract to the ISPO

Site Selection Criteria

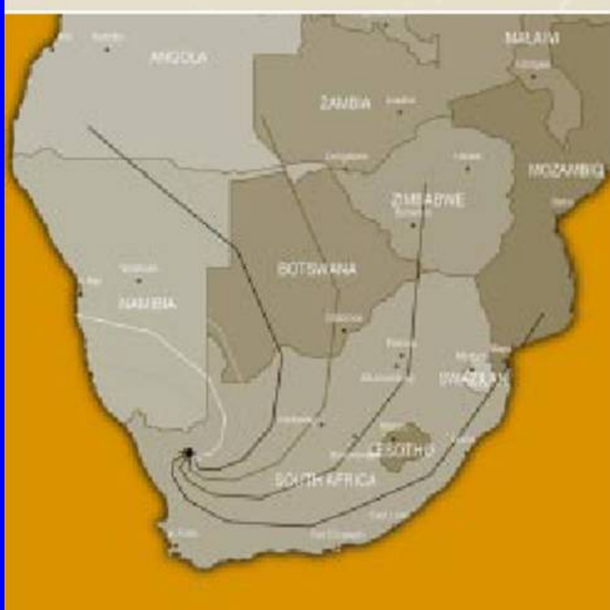
- Science (40%)
  - low frequency (20%)
  - high frequency (20%)
- RFI (20%)
- National conditions (5%)
- Troposphere (5%)
- Ionosphere (5%)
- Physical characteristics (10%)
- Data connectivity (5%)
- Capital and operating costs (10%)

SKA configuration
Western Australia example





Log spiral array map for the Namaqualand Site



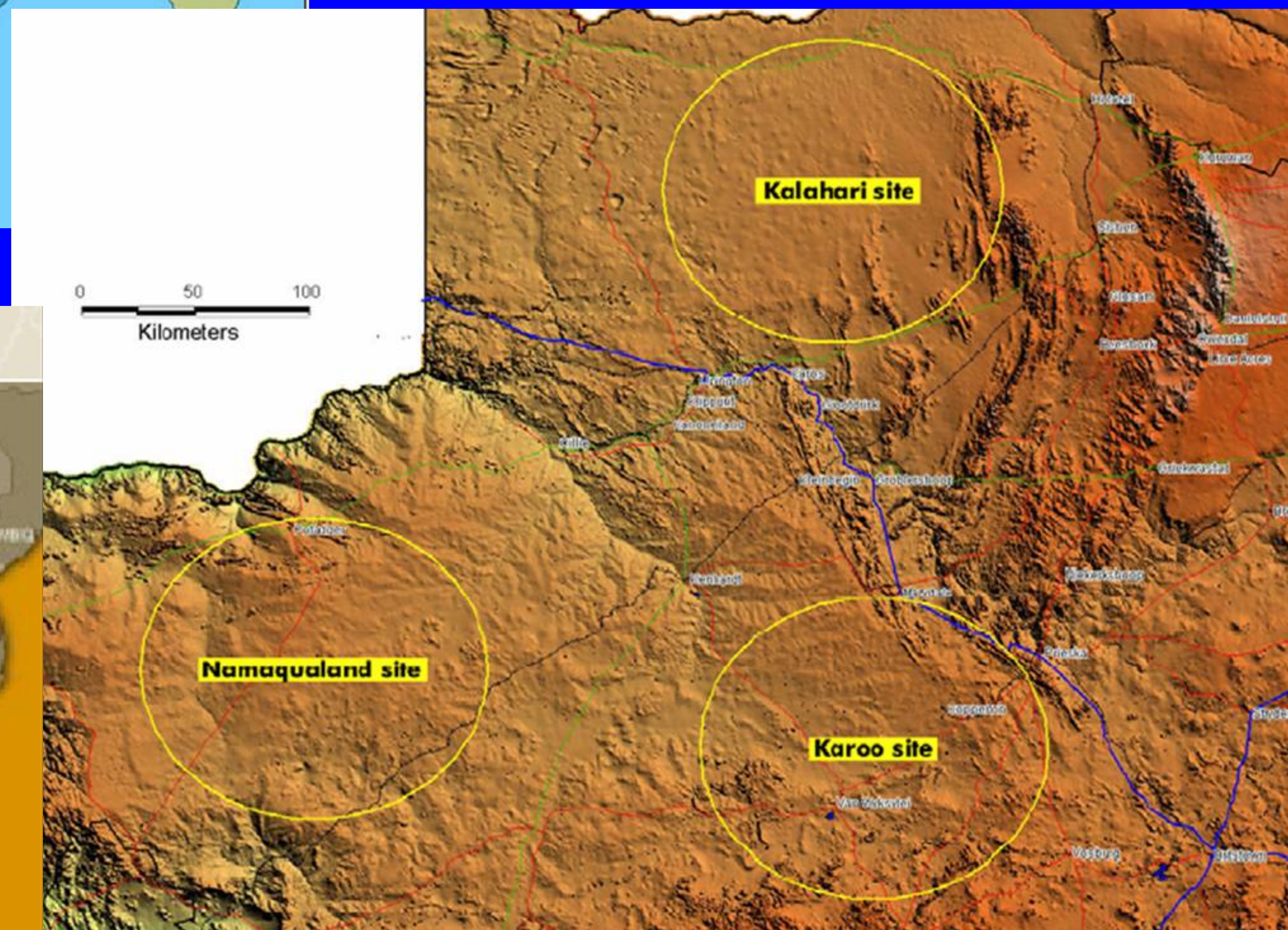
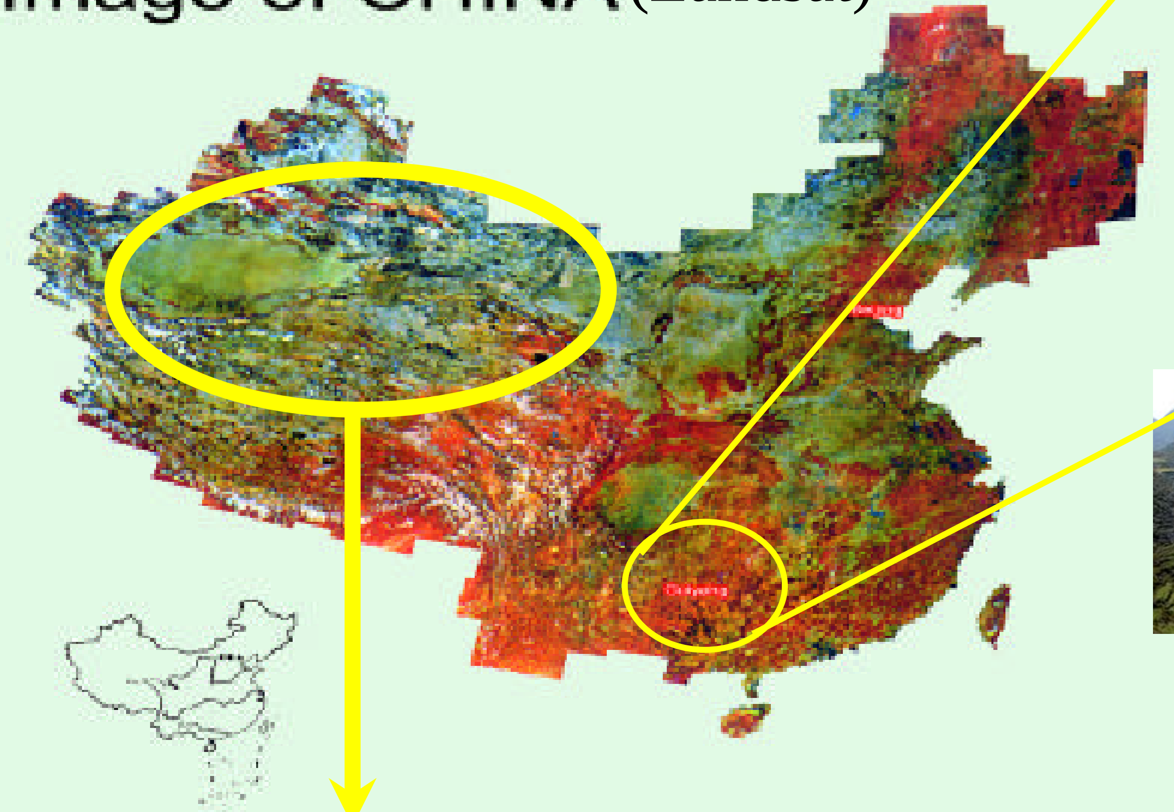
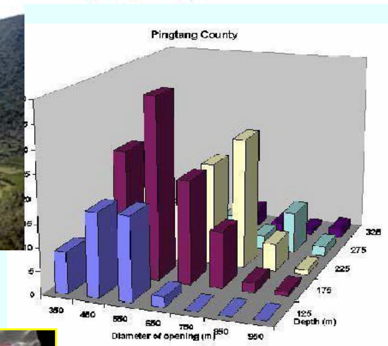
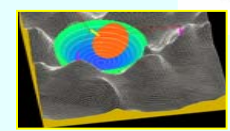


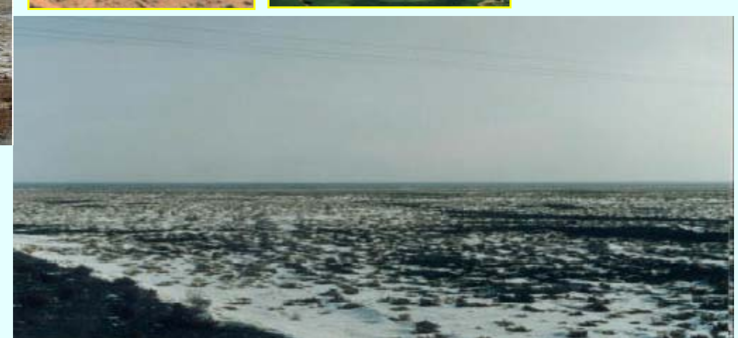
Image of CHINA (Landsat)



KARST







SKA in China

Brazil


VENEZUELA
GUIANA
GUIANA FRANCESA
COLÔMBIA
SURINAME
Boa Vista
RORAIMA
AMAPÁ
Macapá
Equador
Manaus
AMAZONAS
PARÁ
Belém
São Luís
MARANHÃO
Fortaleza
CEARÁ
RIO GRANDE DO NORTE
Natal
Teresina
PARAÍBA
João Pessoa
PIAUÍ
PERNAMBUCO
Recife
ALAGOAS
Maceió
Aracaju
SERGIPE
ACRE
Rio Branco
Porto Velho
RONDÔNIA
Palmas
TOCANTINS
BAHIA
Salvador
PERU
MATO GROSSO
Cuiabá
Brasília-DF
GOIÁS
Goiânia
1
2
3
BOLÍVIA
MINAS GERAIS
Belo Horizonte
ESPÍRITO SANTO
Vitória
MATO GROSSO DO SUL
Campo Grande
SÃO PAULO
RIO DE JANEIRO
Rio de Janeiro
PARAGUAI
São Paulo
Trópico de Capricórnio
PARANÁ
Curitiba
OCEANO PACÍFICO
CHILE
SANTA CATARINA
Florianópolis
RIO GRANDE DO SUL
Porto Alegre
ARGENTINA
OCEANO ATLÂNTICO
URUGUAI
5°
0°
5°
10°
15°
20°
25°
30°
35°
75°
70°
65°
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45°
40°
35°
30°

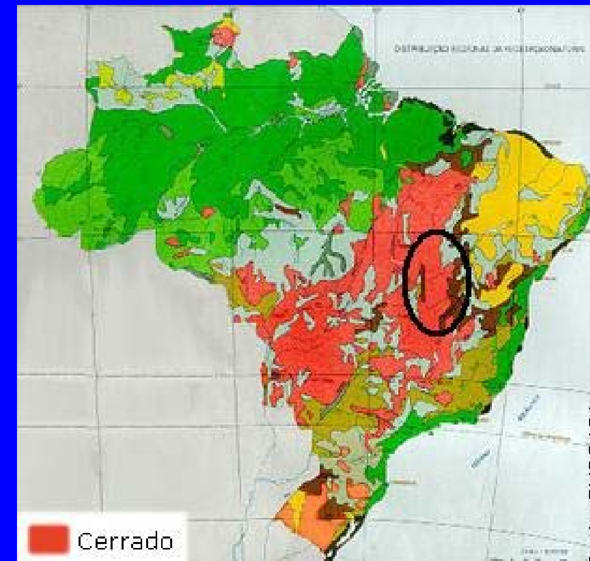
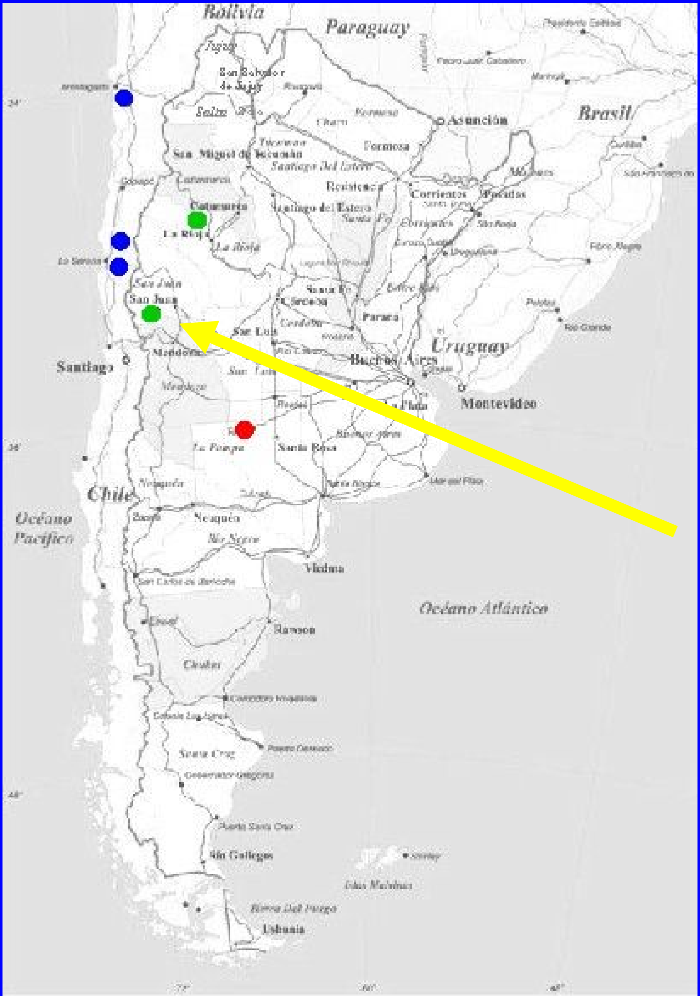

Cerrado
Fonte: EMBRAPA


Foto: L.M. Coutinho

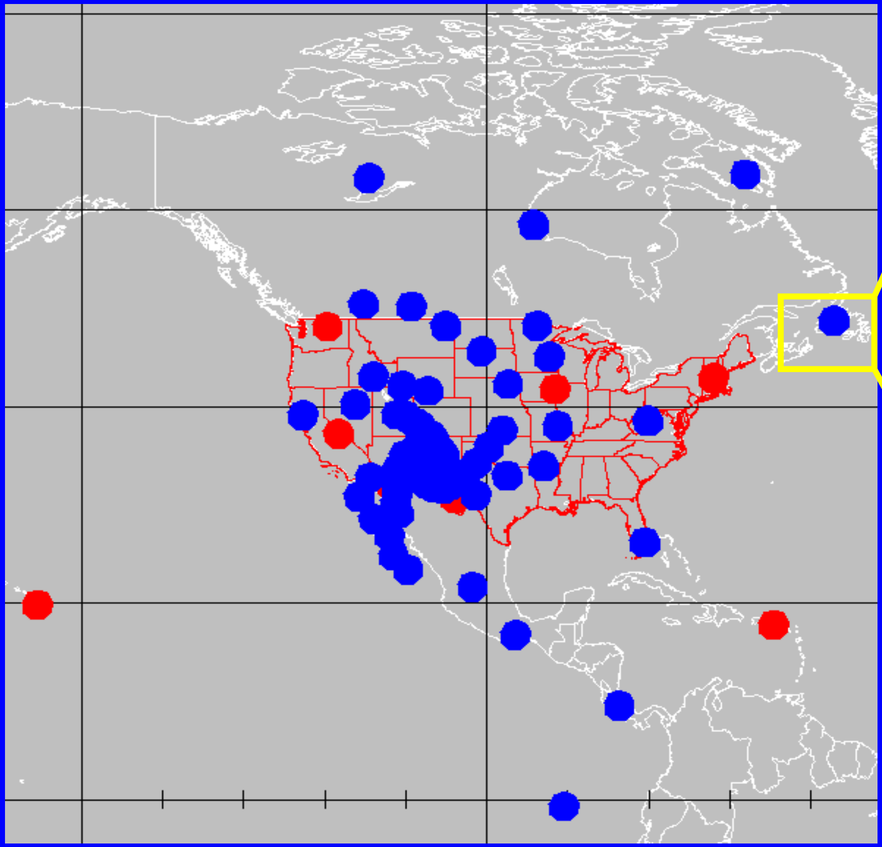
SKA in Argentina

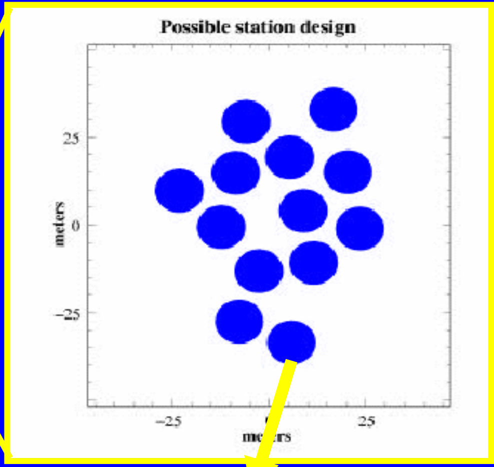


U.S. Proposal
North American Array
Most of antennas in New Mexico
About half the collecting area at or near VLA site

- Large, high, dry, site (VLA) is ideal
- Extensive infrastructure already in place in NM
  - Land, roads, fiber, personnel, universities, federal labs, national observatories
- RFI protection
- Existing long term site studies for VLA
- Co-location with VLA+VLBA allows phased development

US – Large-N/Small-D





84 stations
35-350 km

76 stations
350-3500 km

Inexpensive, hydroformed dishes

2320 12m antennas within 35 km core

US SKA Consortium

Purpose: to coordinate SKA activities in the U.S.

Chair: Yervant Terzian (Cornell)

Vice Chair: Jack Welch (UCB)

Caltech/JPL
Cornell/NAIC
Harvard/Smithsonian
MIT/Haystack
NRAO
NRL
SETI Institute
University of Illinois
University of Minnesota
University of New Mexico
University of Wisconsin
UC Berkeley
Virginia Tech

5-year Technology Development Project

- Work plan now being developed by the US SKA Consortium
- Proposal submitted to the NSF
- 7 main work areas:
  - **Antennas and receivers**
  - **Digital signal transport and processing**
  - **Systems design and analysis**
  - **Siting**
  - **Operations and costing**
  - **The ATA as a testbed for SKA feeds, receivers, RFI, large-N ops**
  - **Outreach**

US SKA Prototype Activities

Allen Telescope Array (SETI)	**DSN Array 16,000 m^2/K**	**EVLA 1000 m^2/K**
350 6m dishes 0.5-11GHz	3 x 3600 x 12m dishes freq =8/32GHz	45 25m ants 0.3-90 GHz (VLA+NMA+VLBA)
2003-First antenna, prototype correlator 2004-Construction begins 2006-Full operation (depends on NSF support for radio astronomy imaging)	2003 6m prototype 2004 2x6m interferometry 2009 4 x 25x12m clusters **Problem!** **Symmetric Antennas**	2001 Start Upgrade 2006 Start NMA construction 2012 NMA Operation

LOFAR

The Low Frequency Array

Haystack, Astron, NRL, SWC*

Frequency: 10-240 MHz
Size: 400 km. 100 patches
Resolution : 2-20 arcsec
Elements: 2 x 13,000 dipoles
Sky coverage: Multiple beams
Location:
- SW United States (NM)
- Western Australia
- Netherlands

Time Table
- PDR June 2003
- Site Selection late 2003
- Initial Operations 2006
- Full Operations 2008

*UNM, LASL,U Tex, NMS, NM Tech

SKA: How much will it cost?

4400 x 12 m antennas	$ 660 M
Receivers	170
Data transmission	40
Civil costs (central site)	65
Civil costs (outer configuration)	135
Signal processing	80
Computing hardware	80
Software development (660 man years)	50
Non-recurring engineering	60
Contingency (20%)	270
Total	**$1,610 M**

Who is going to Pay for it?

- Plan 1
  - U.S. 1/3
  - Europe 1/3
  - RoW (Canada, Australia, Asia, Africa) 1/3
- Plan 2:
  - North America 40%
  - Europe 40%
  - RoW (including Japan) 20%

How much will it cost to operate

Operations Staff	36 FTE's	$ 1.8 M/year
Scientific Staff	30	3.0
Computing Hardware Support	10	0.9
Computing systems plus M/C	40	4.0
Data management	10	1.2
Central engineering	150	12.0
Distributed engineering	240	19.2
Administration	50	4.0
Fiber rental		10+???
M&S		15.4
Upgrades (3% construction)		50.0
User support (3% construction)		50.0
Total annual operating cost		**$ 171.5 +???M**

Challenges for the SKA

- Constructing a cost effective SKA
  - Antenna elements
  - High data rate signal transfer
  - High dynamic range imaging
  - RFI excision
  - Correlator
- Intellectual Property Rights/ITAR
- Confusion levels - natural confusion
- Funding an international project?
  - SKA was international from the start
  - Different funding cultures in each country
- Continued broad participation after site and concept selection – “mutual convergence.”
  - US Consortium is committed to “best site-best science”
- Cost effective operations

<www.skatelescope.org>