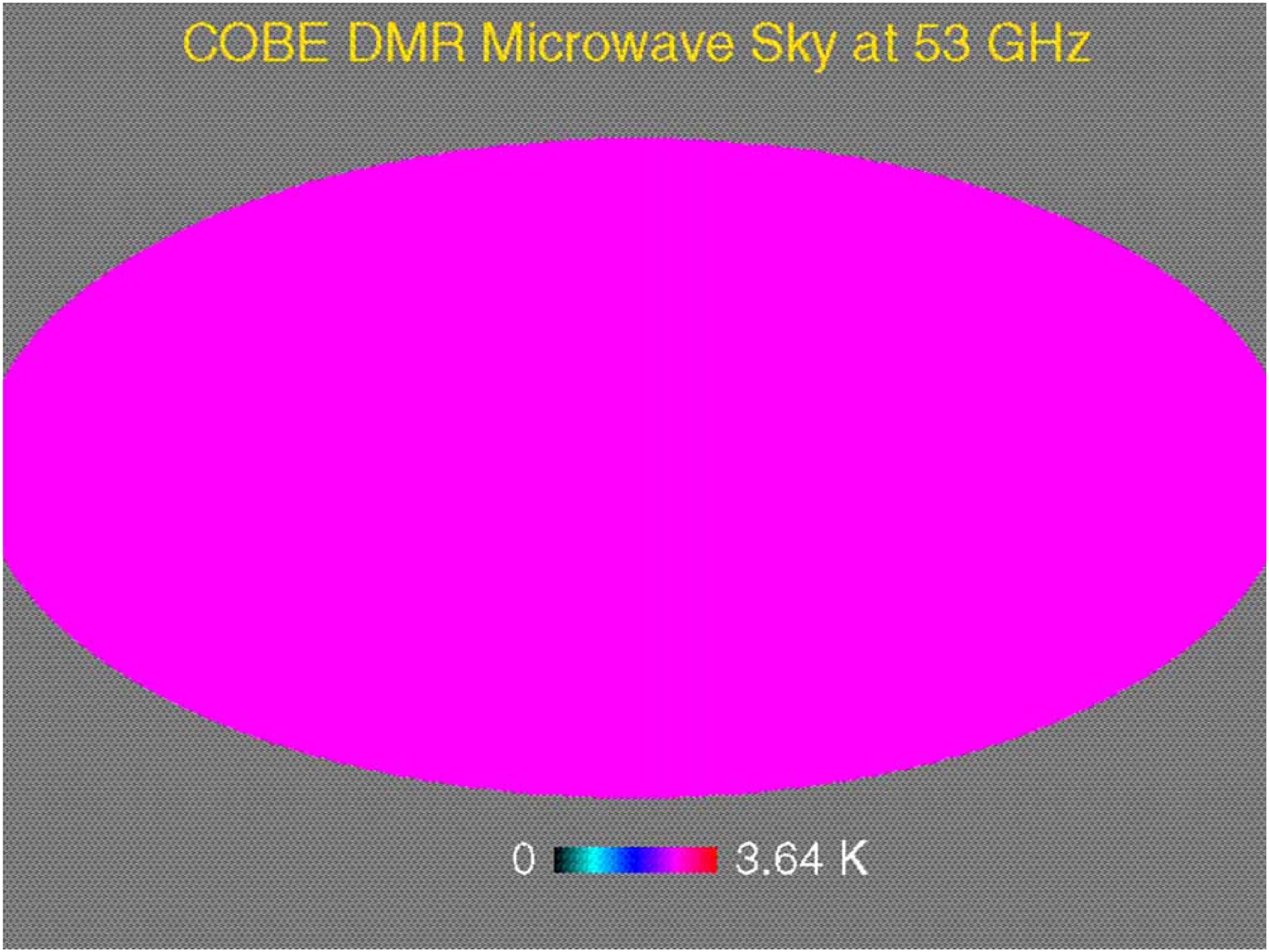
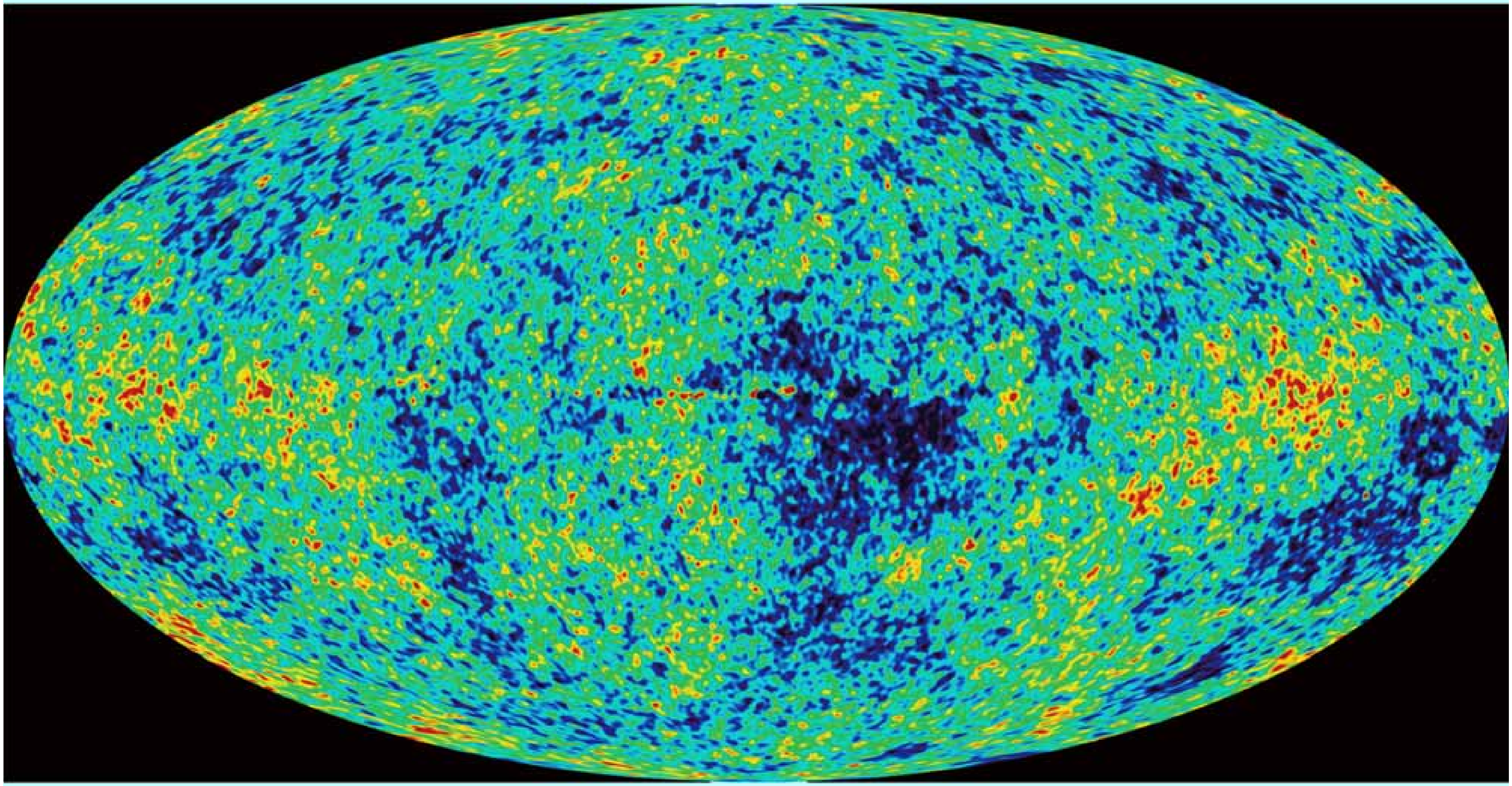
# Square Kilometer Array

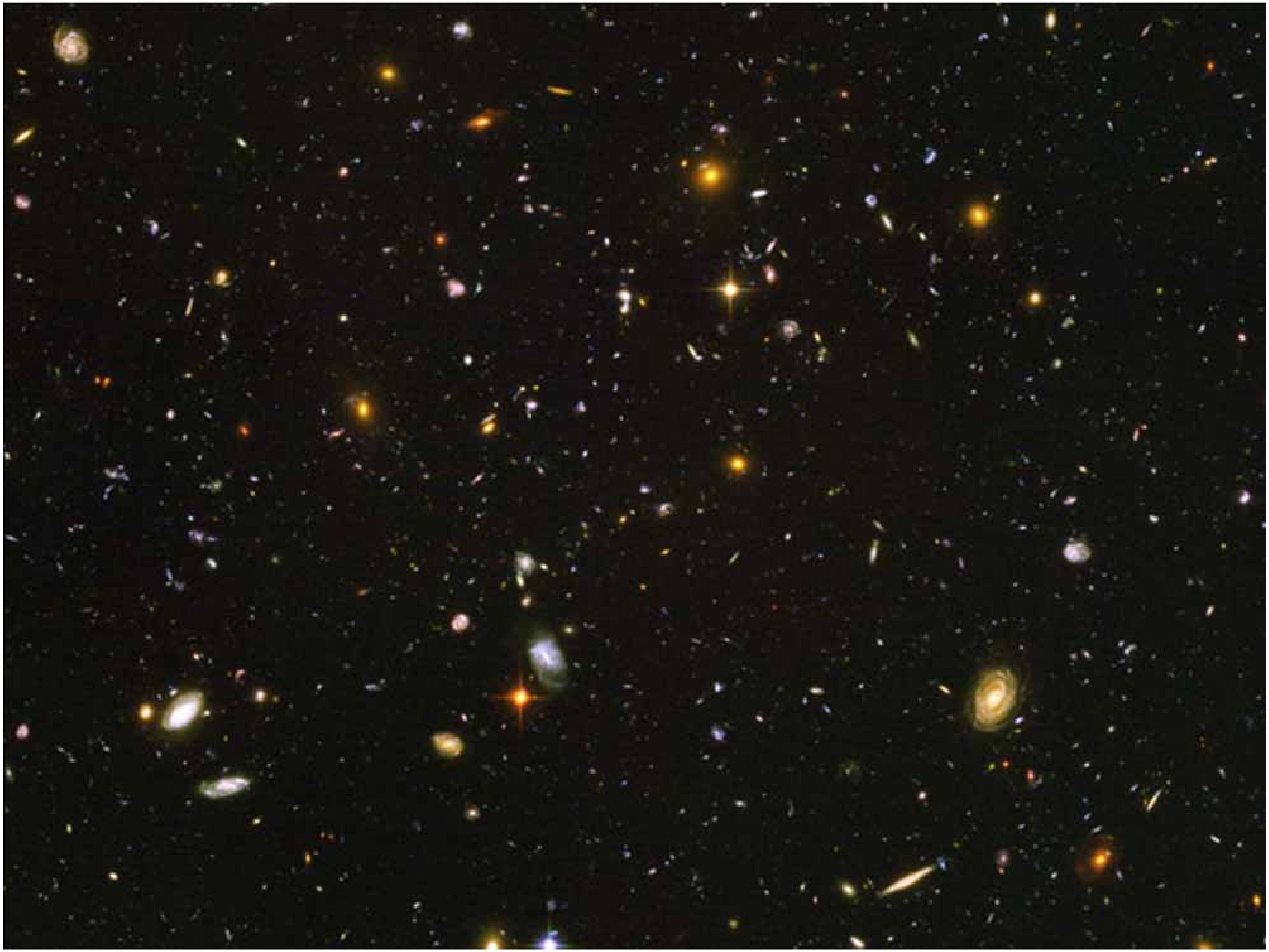
**YERVANT TERZIAN**

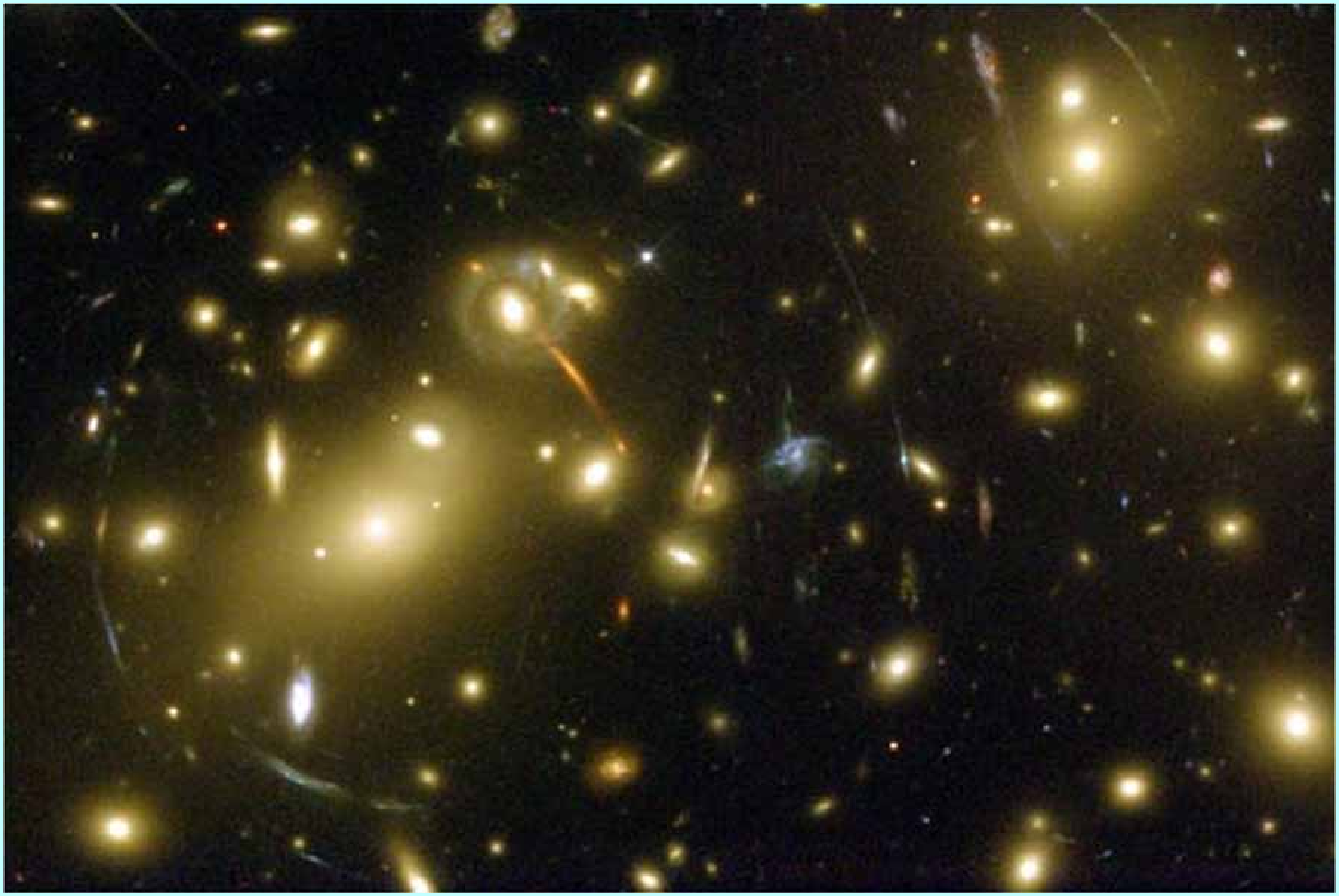
**CORNELL UNIVERSITY**

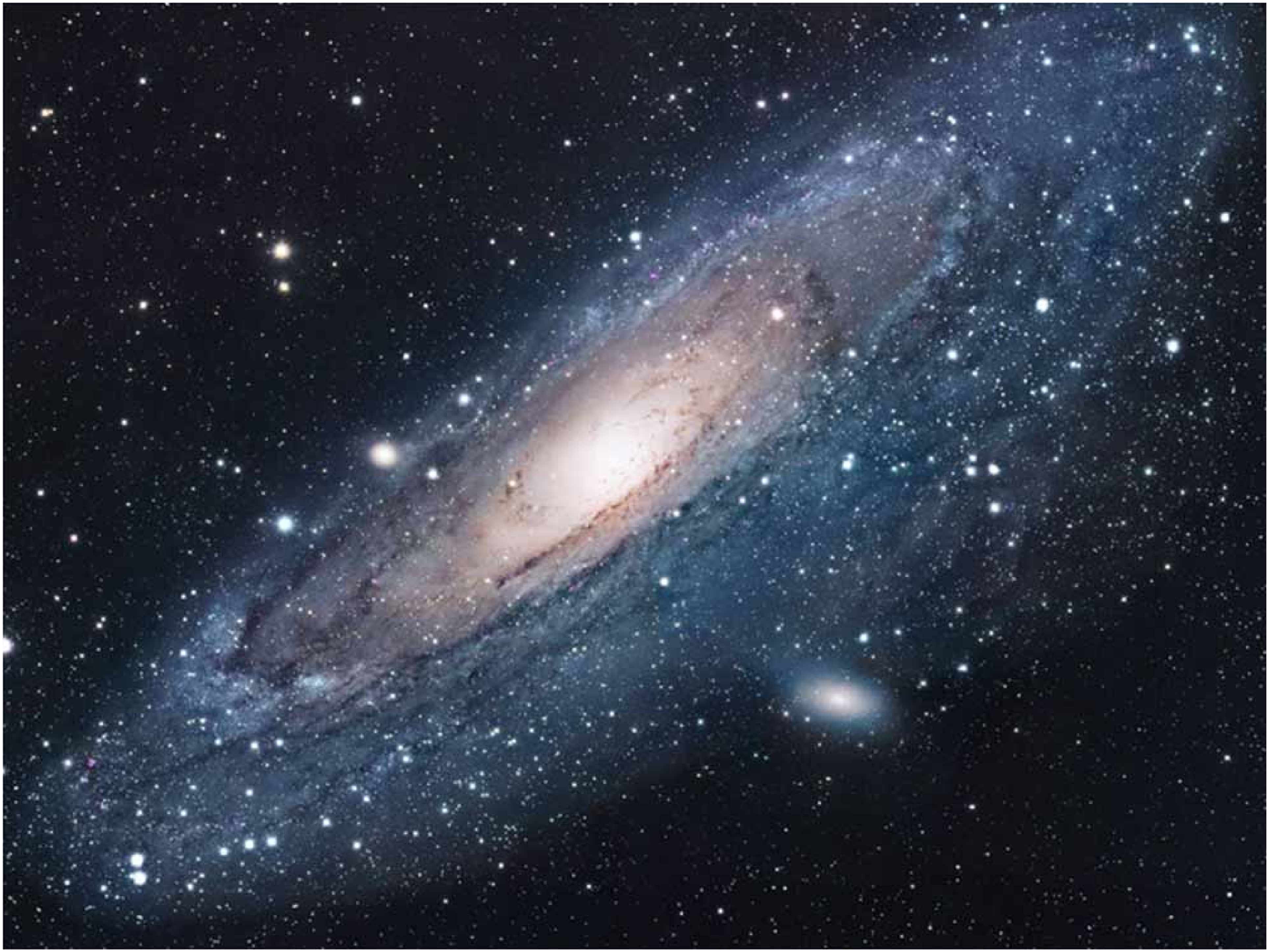
<www.skatelescope.org>

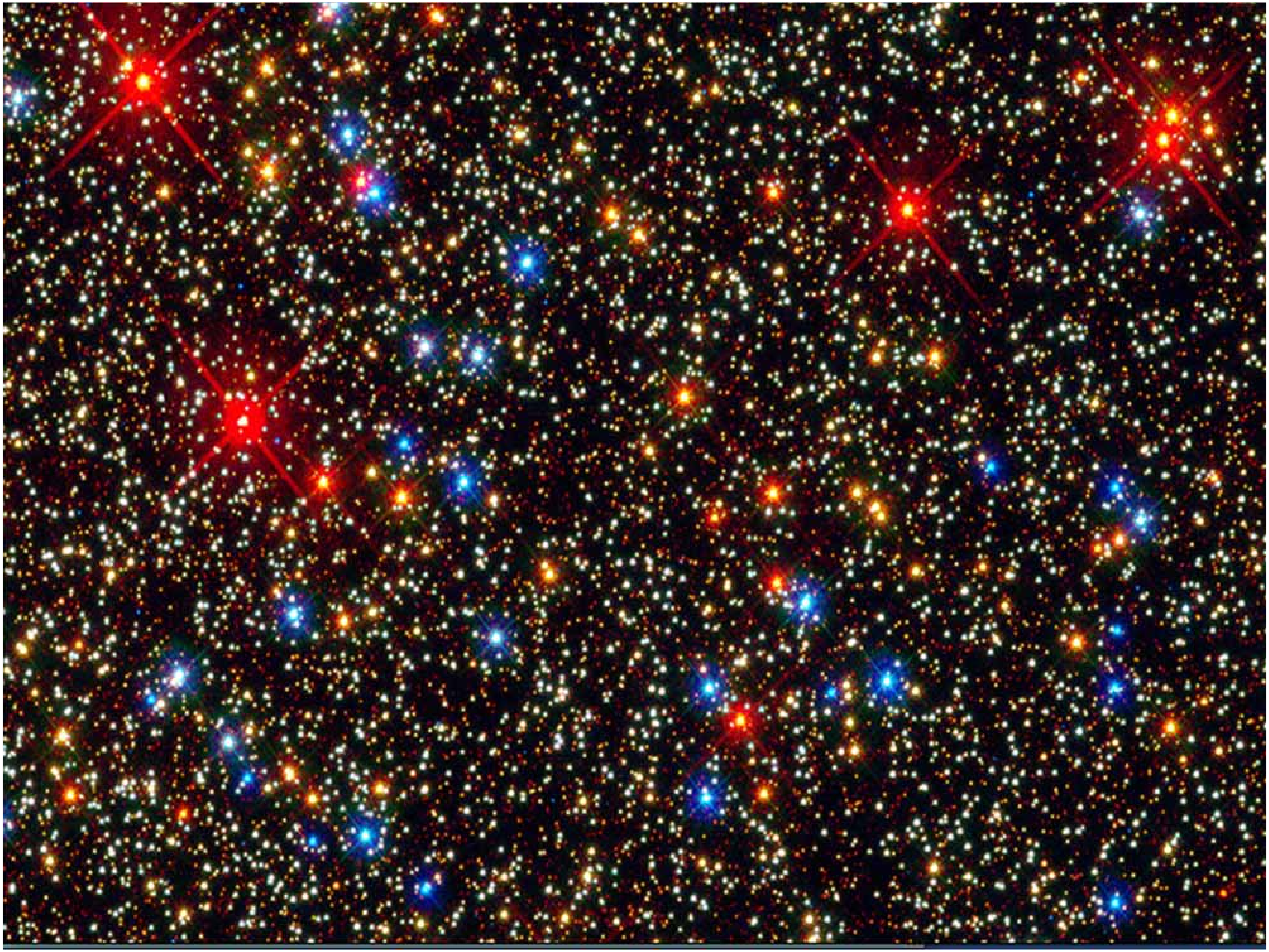

COBE DMR Microwave Sky at 53 GHz
0
3.64 K

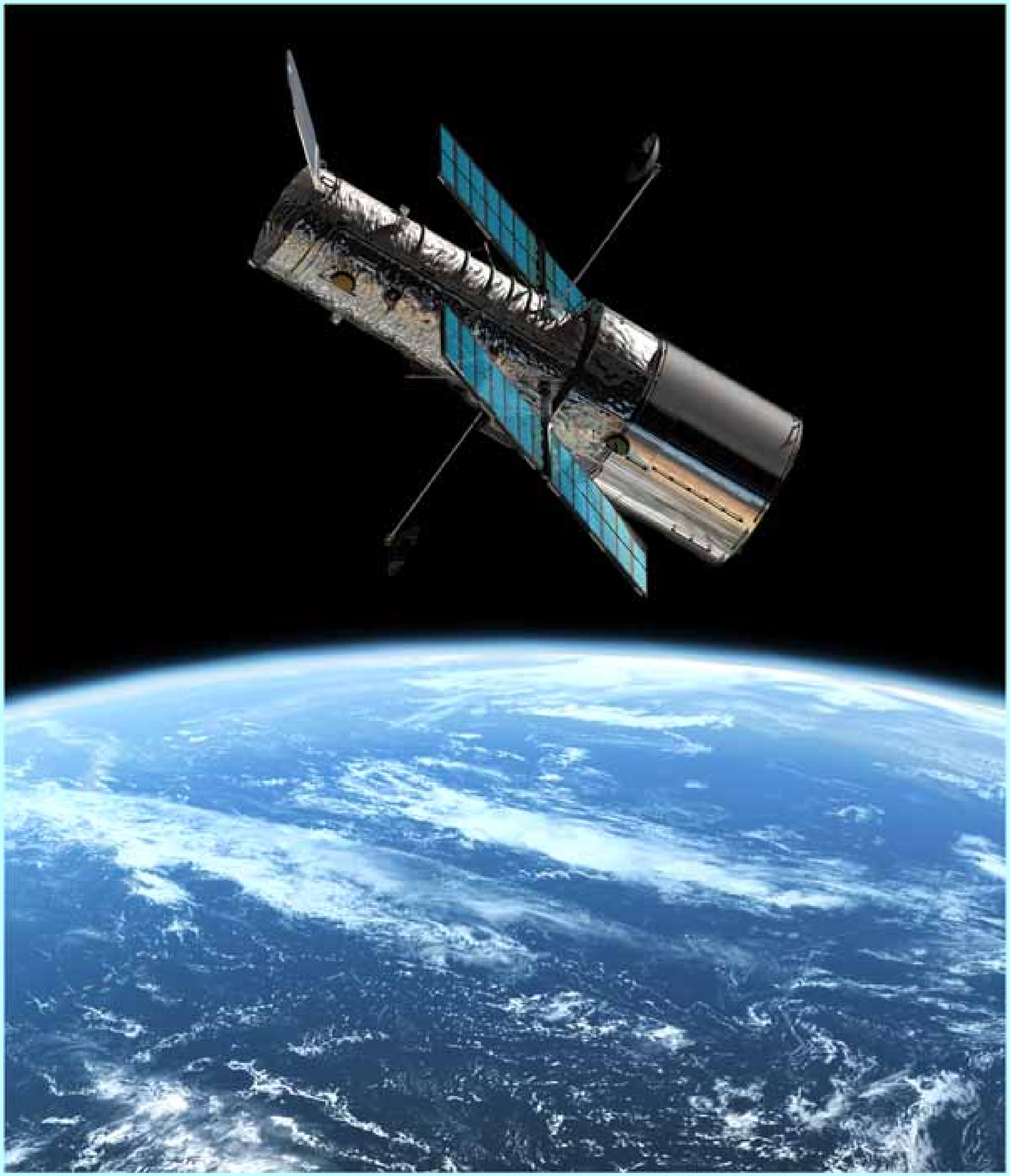


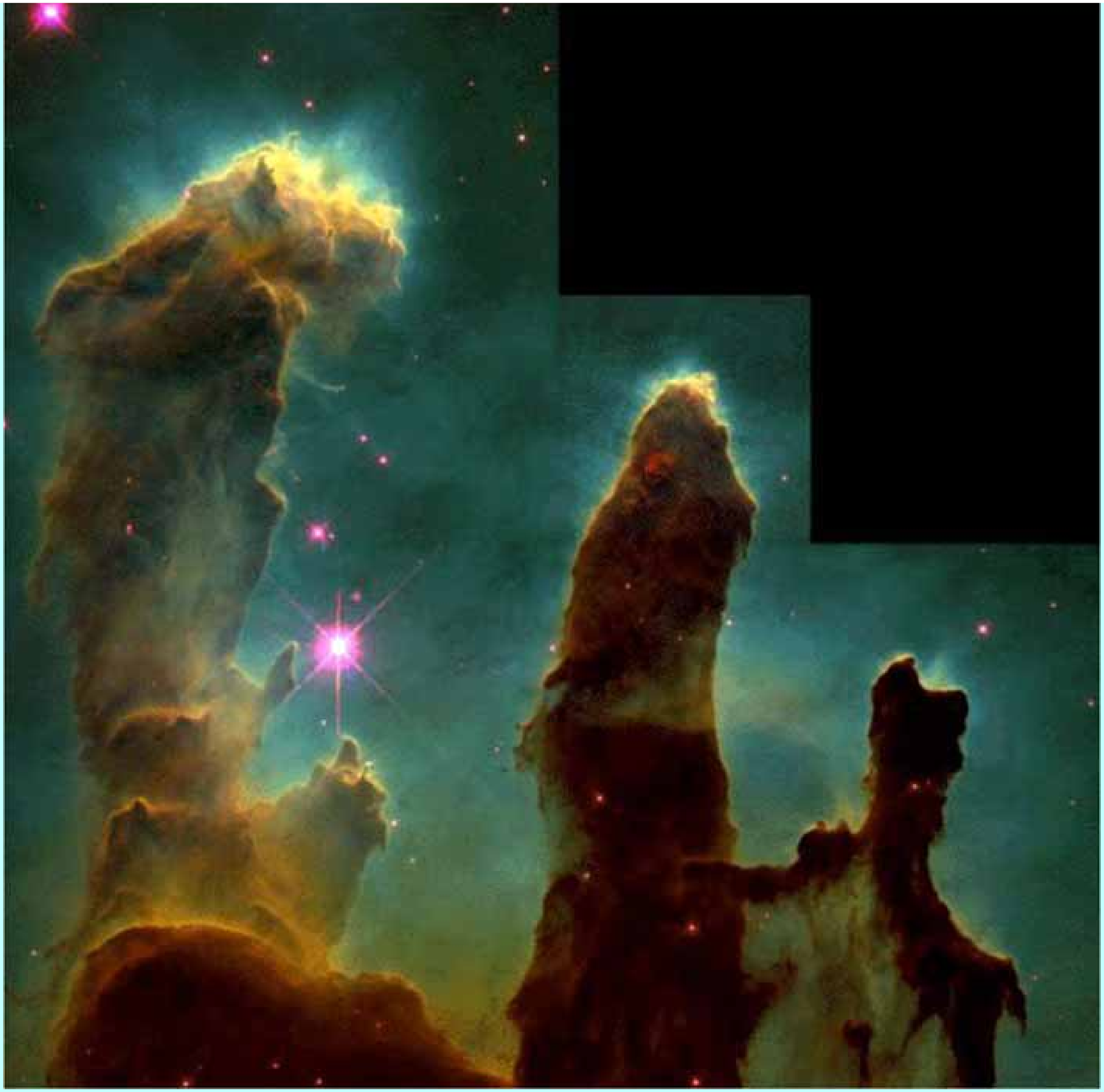




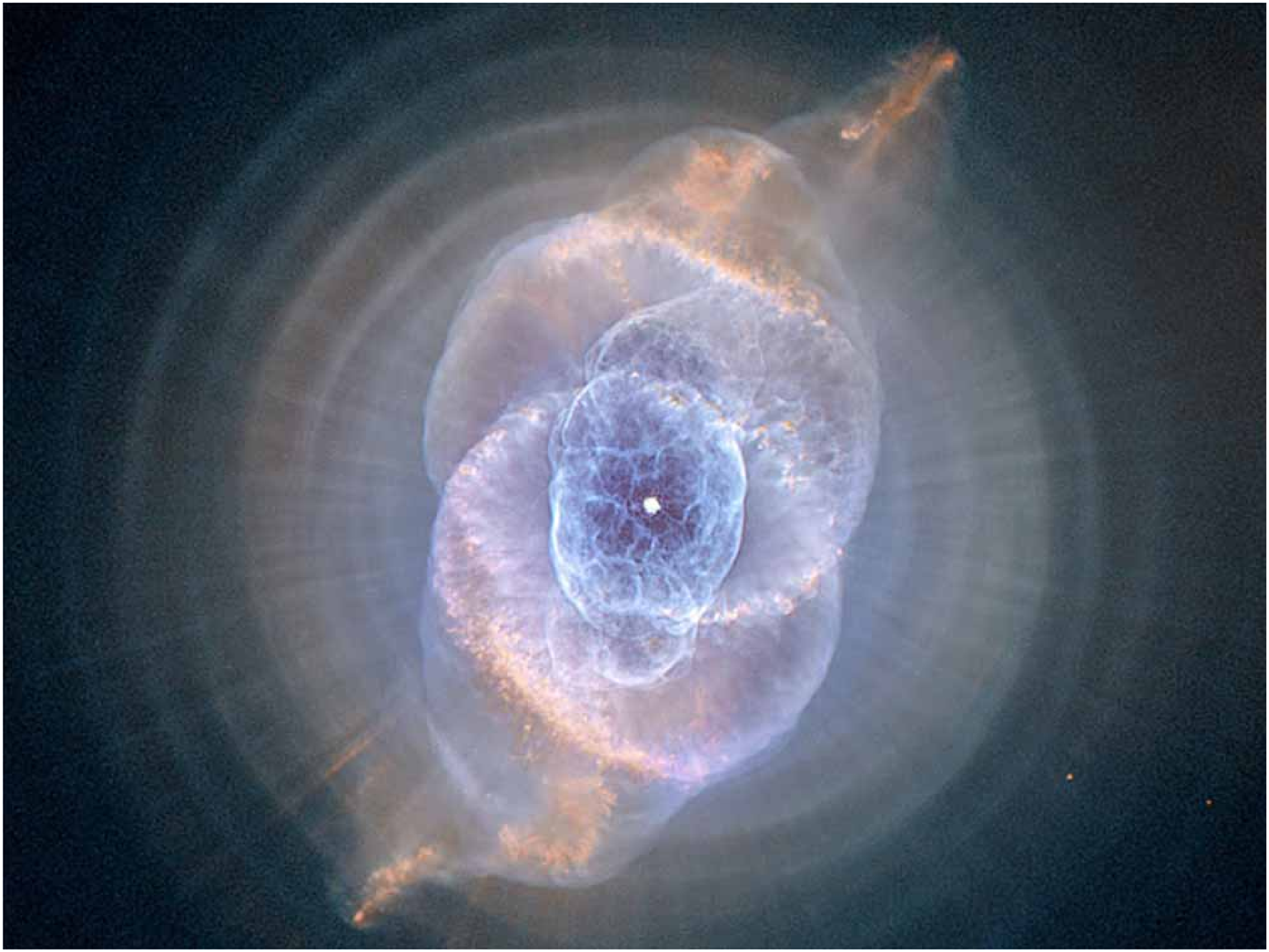


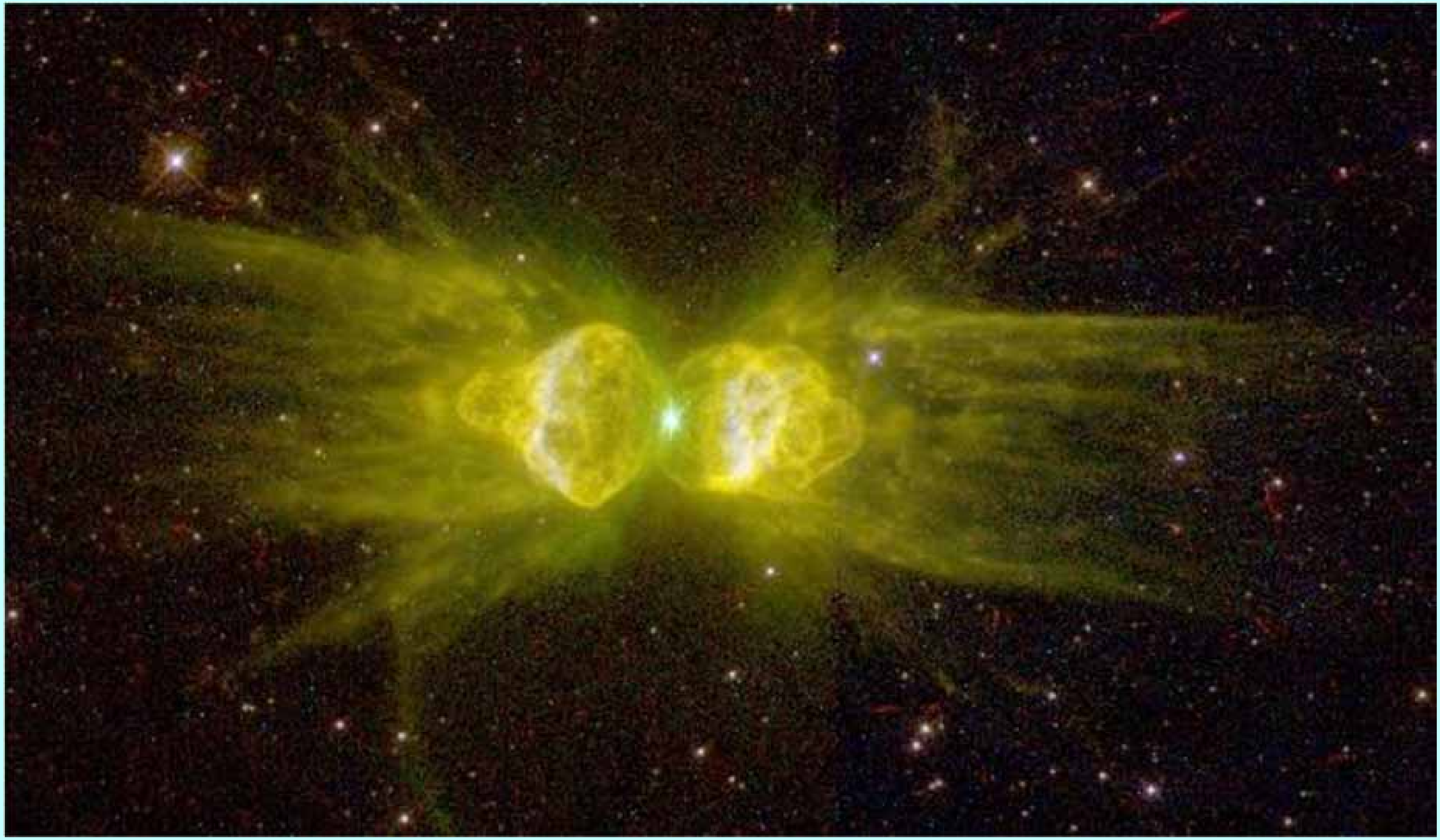


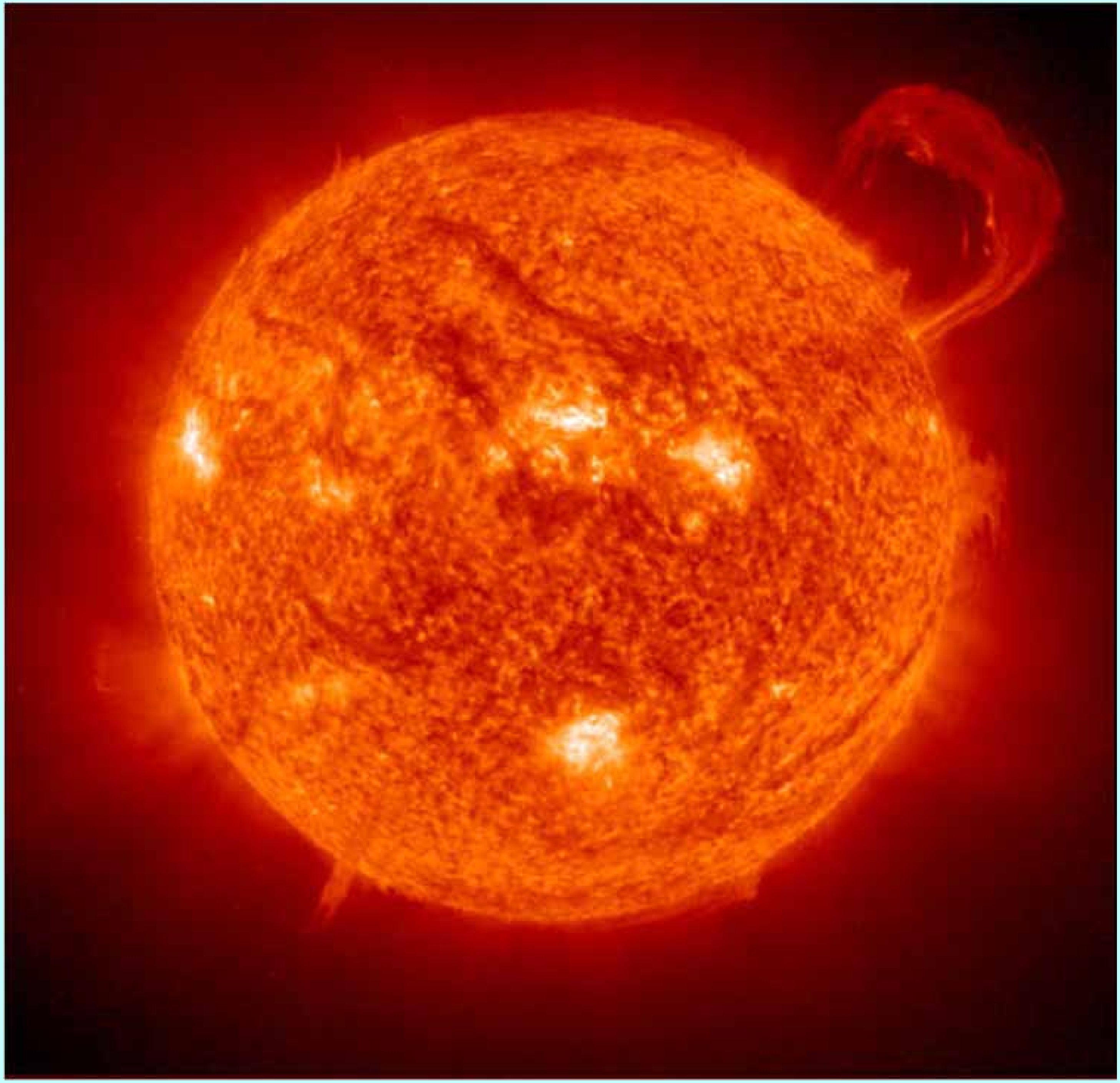


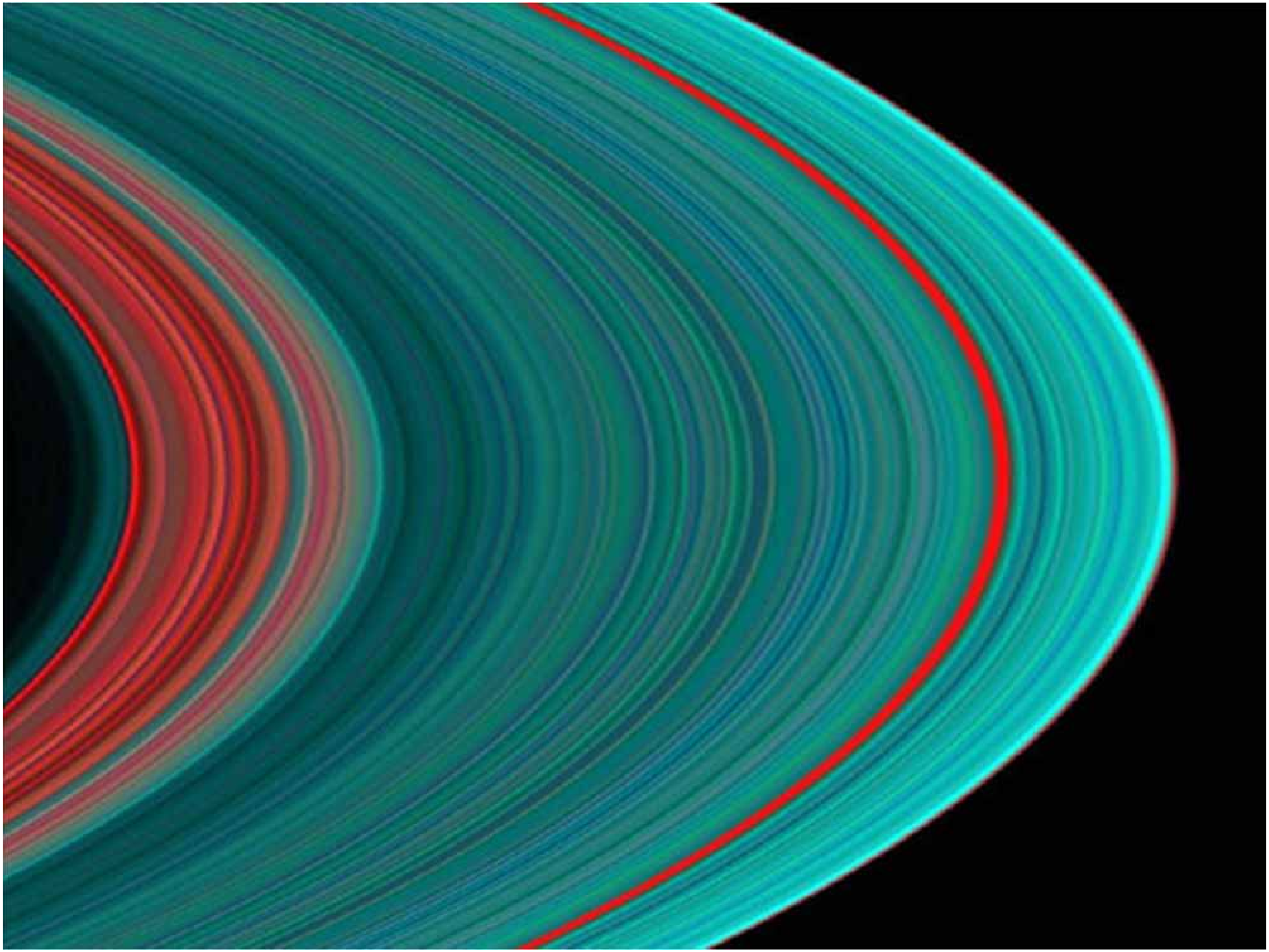


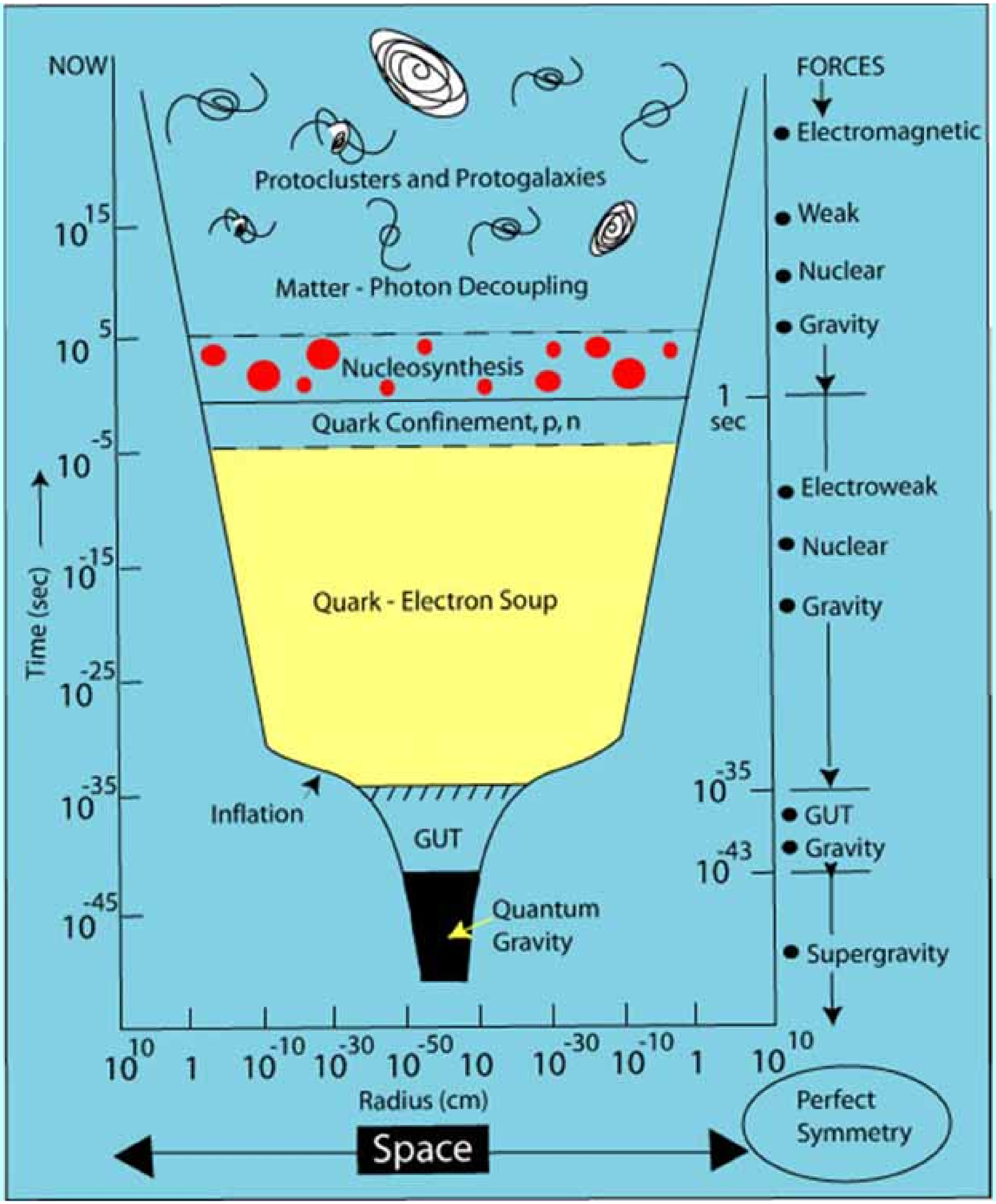

Daniel López IAC (Isaac Newton Telescope, INT)







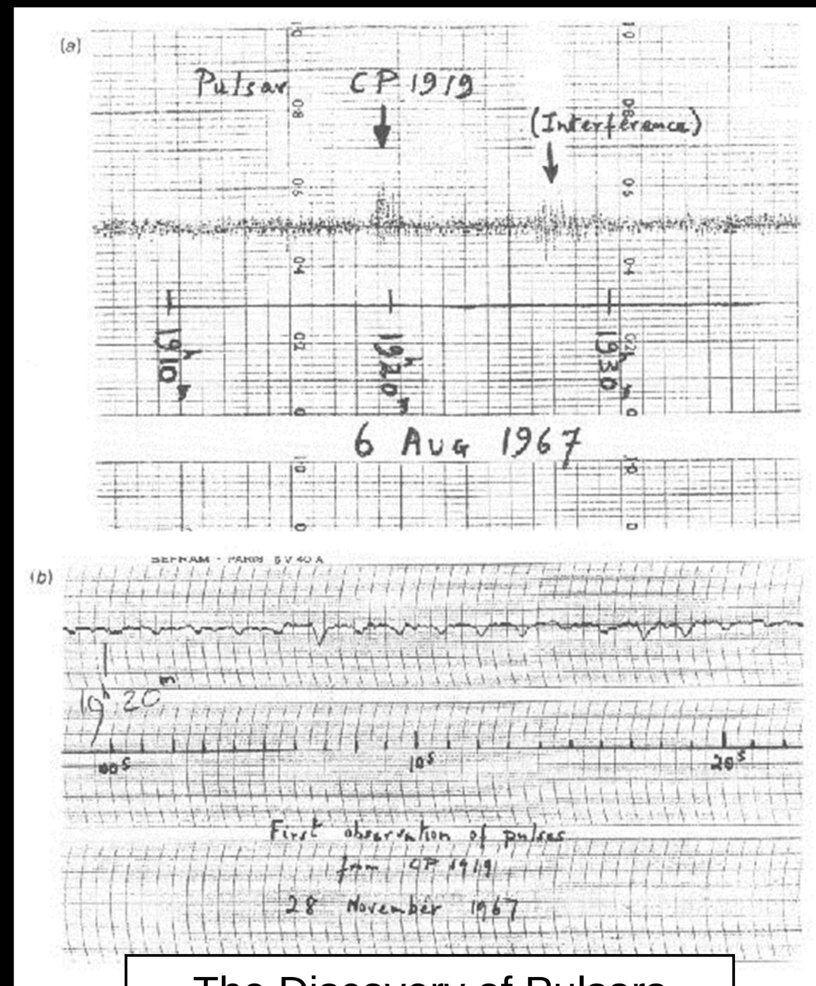





# The Big Bang Space Time

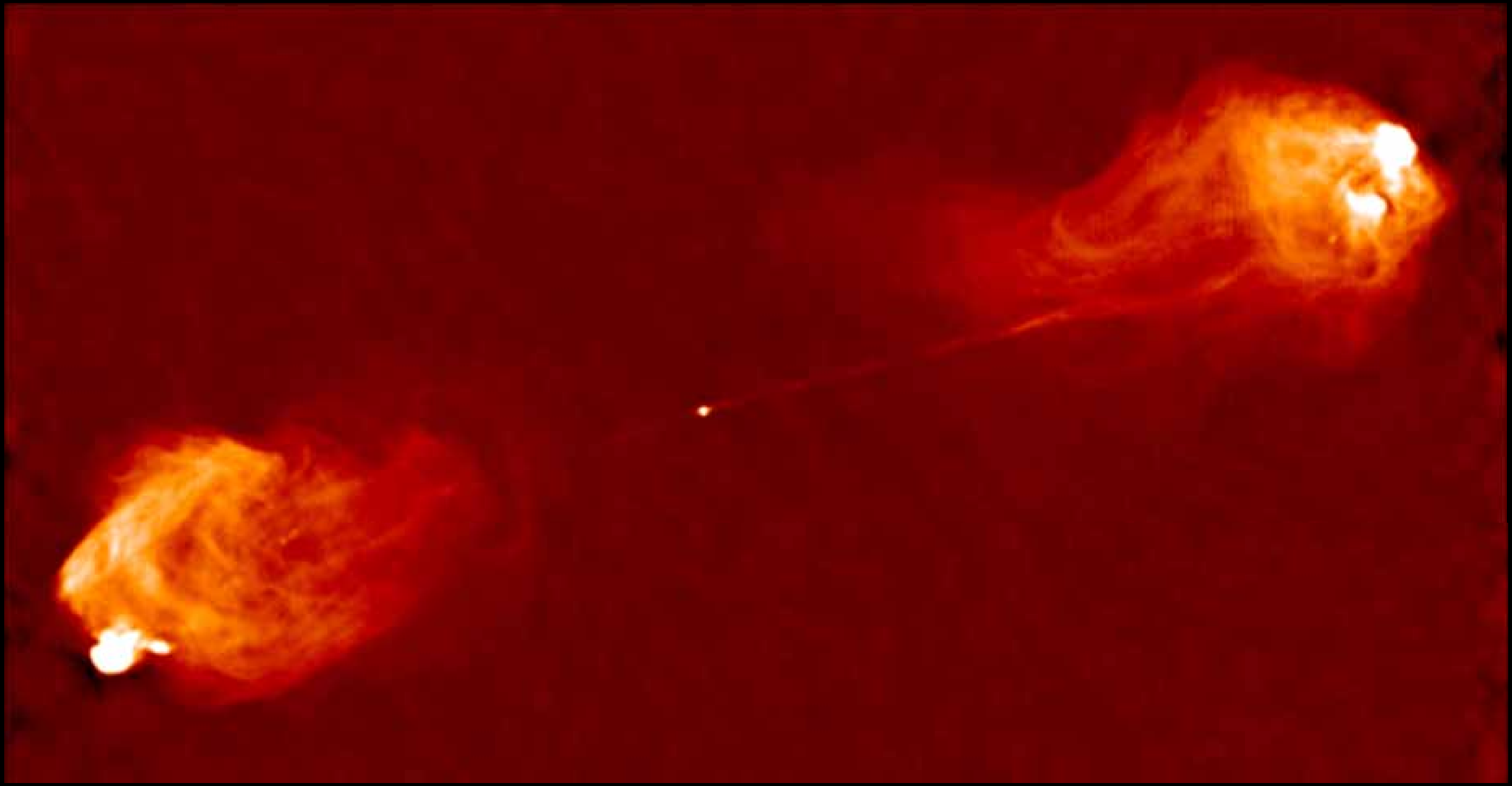
# A rich history of discovery

- Many discoveries over the past 50yr
  - Pulsars 
  - Microwave Background 
  - Cosmic Evolution
  - Dark Matter in galaxies
  - Quasars
  - Jets + Superluminal motion
  - Gravitational Radiation 
  - Aperture Synthesis 
  - Cosmic Masers
  - Giant  Molecular Clouds



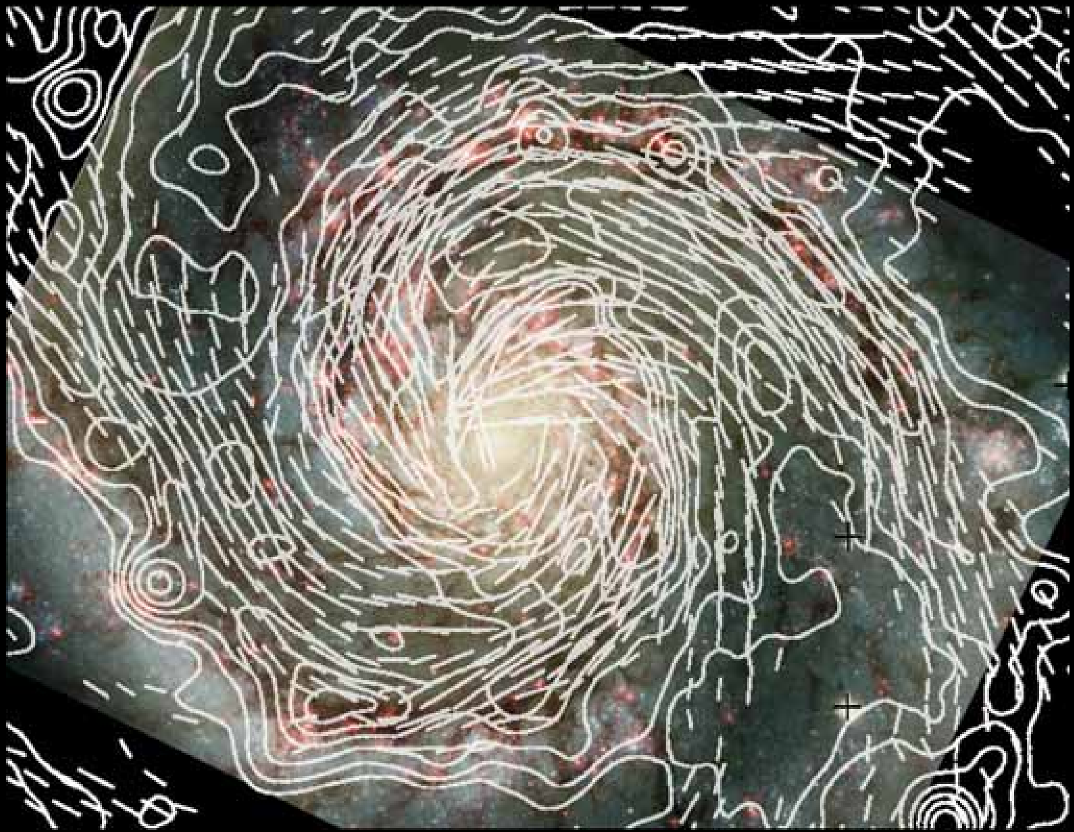

The Discovery of Pulsars

# Radio provides unique information about the Universe



Non-thermal processes: quasars, pulsars, jets

# Radio provides unique information about the Universe



Tracer for Cosmic Magnetic Fields

# Fundamental Questions in Physics and Astronomy

**“What are the basic properties of the fundamental particles and forces?”**

Neutrinos, Magnetic Fields, Gravity, Gravitational Waves, Dark Energy

**“What constitutes the missing mass of the Universe?”**

Cold Dark Matter (e.g. via lensing), Dark Energy, Hot Dark Matter (neutrinos)

**“What is the origin of the Universe and the observed structure and how did it evolve?”**

Atomic hydrogen, epoch of reionization, magnetic fields, star-formation history……

**“How do planetary systems form and evolve?”**

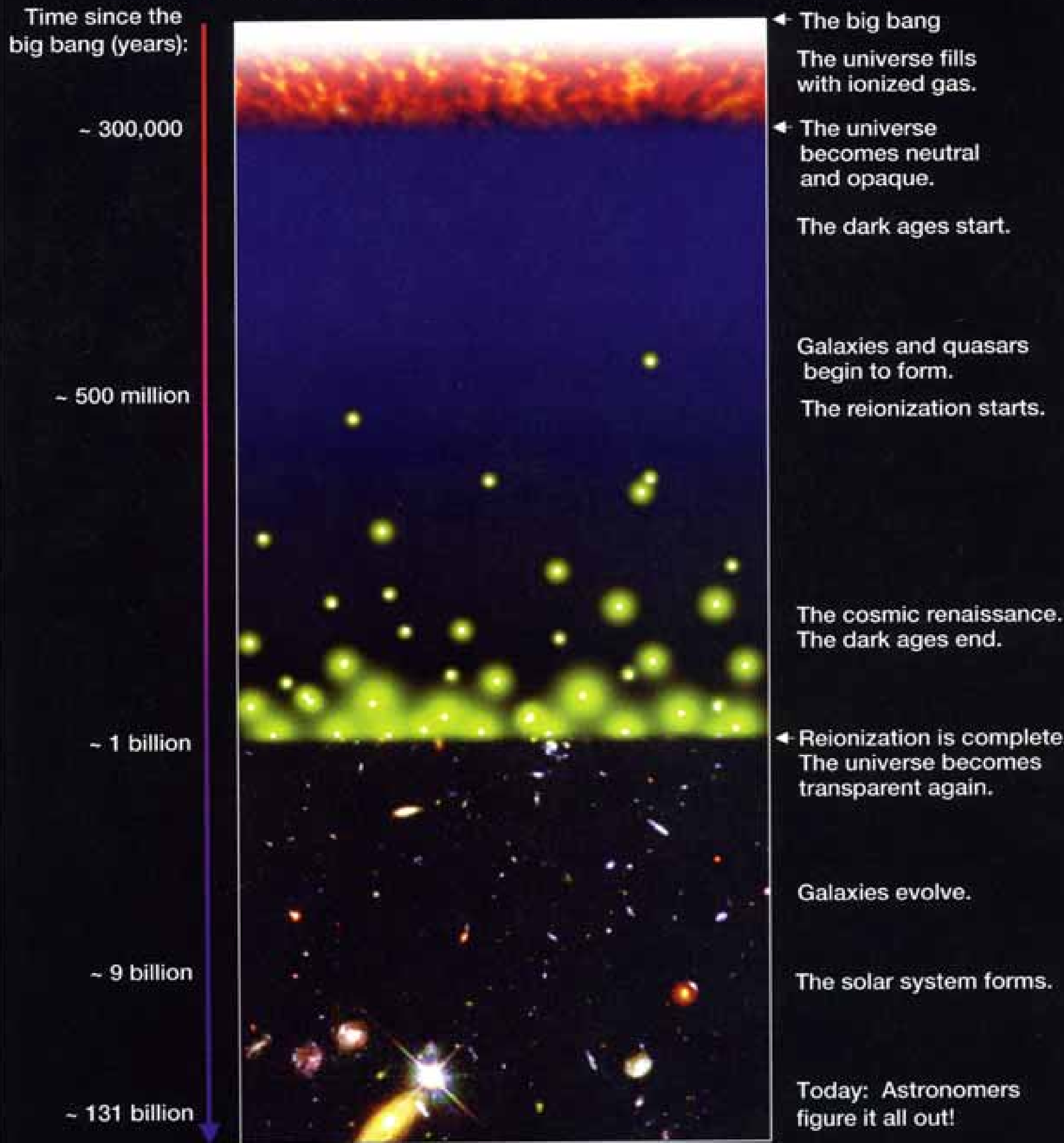
Planet Formation, Astrobiology, Radio flares from exo-planets……

**“Has life existed elsewhere in the Universe, and does it exist elsewhere now?”**

SETI

# What Is the Reionization Era?

## A Schematic Outline of the Cosmic History



# Top Priorities for a New Generation Radio Telescope

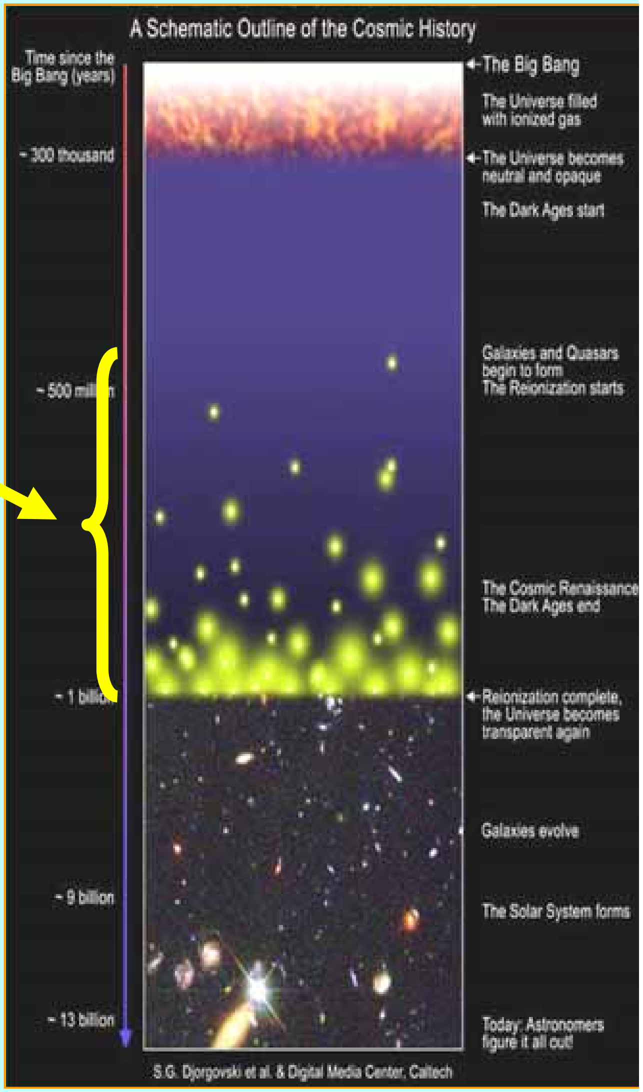
- Detect and image neutral hydrogen in the very early phases of the universe when the first stars and galaxies appeared
– "epoch of re-ionisation"

- **Locate 1 billion galaxies via their neutral hydrogen signature and measure their distribution in space – "dark energy"**

- **Origin and evolution of cosmic magnetic fields – "the magnetic universe"**

- **Time pulsars to test description of gravity in the strong field case (pulsar-Black Hole binaries), and to detect gravitational waves**

- **Planet formation – image Earth-sized gaps in proto-planetary disks**



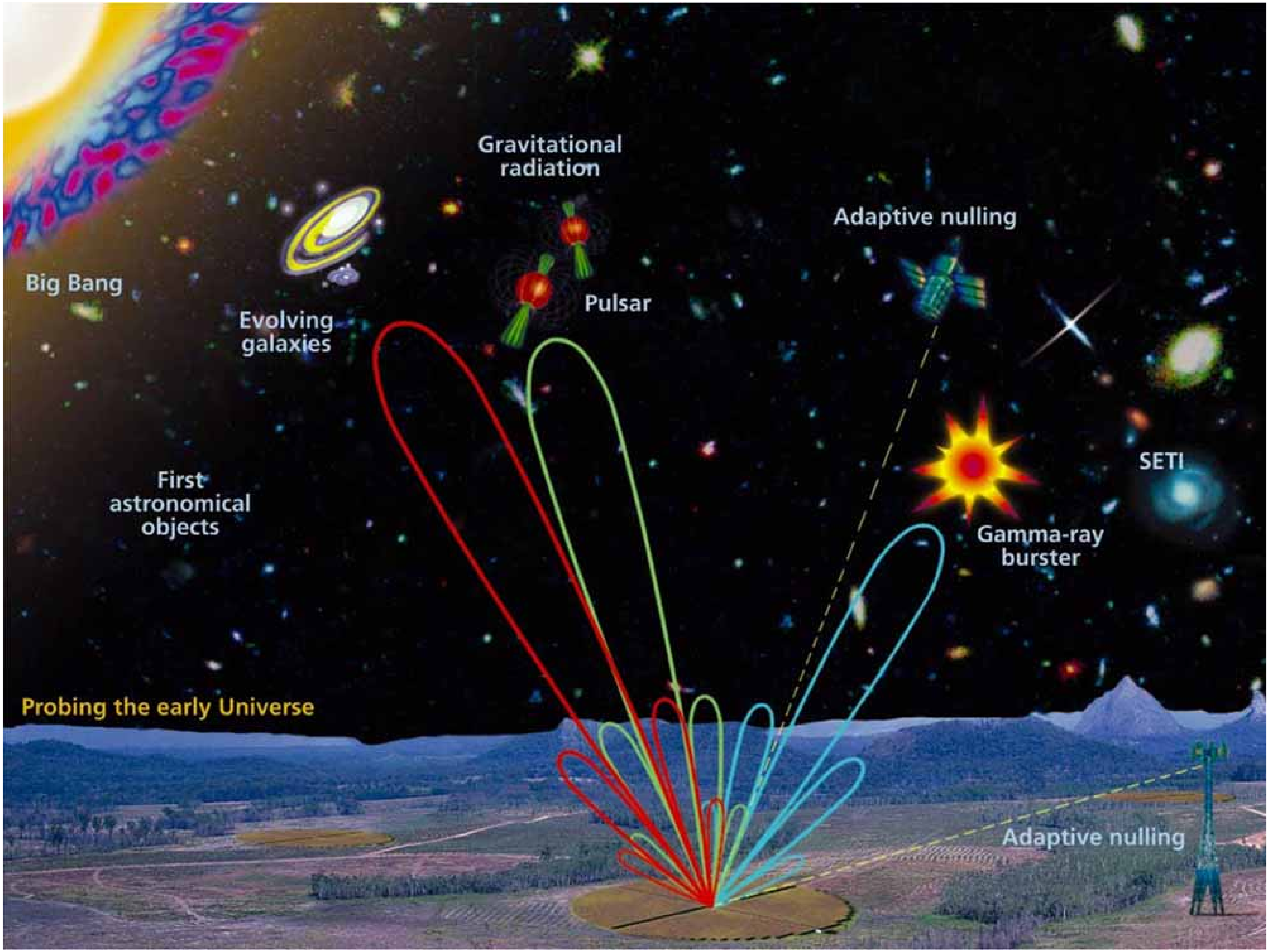
# What instrument do we need?

A radio telescope with

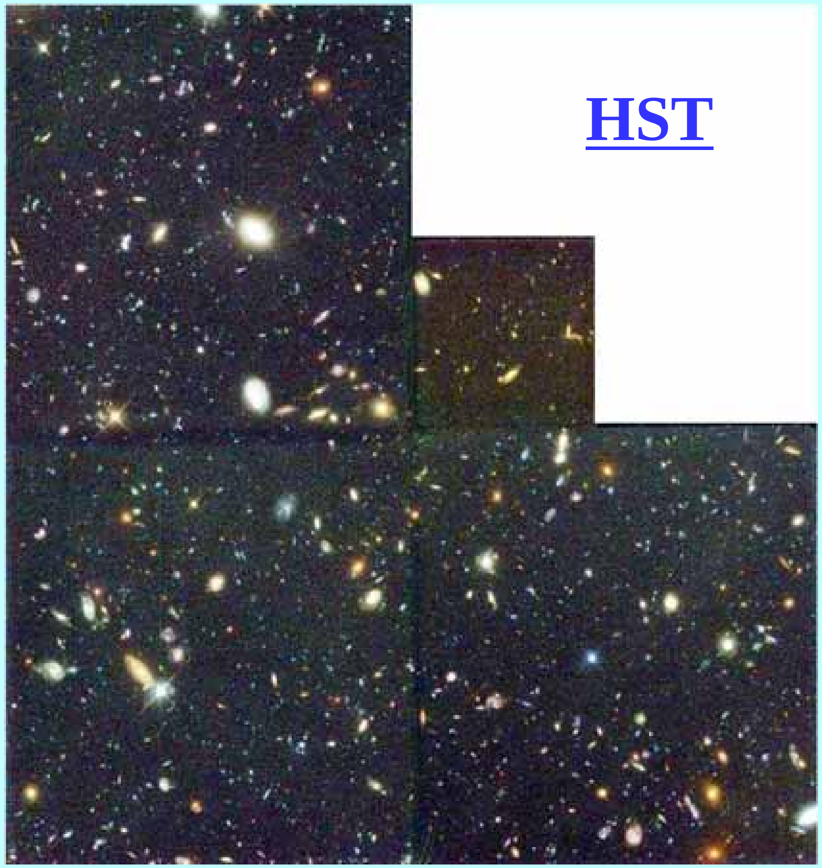
- **sensitivity to detect and image atomic hydrogen at the edge of the universe →** ***very large collecting area***
- **fast surveying capability over the whole sky →** ***very large angle field of view***
- **capability for detailed imaging of the structures of the planetary gaps and how they change →** ***large physical extent***
- ***a wide frequency range*** **to handle the science priorities**

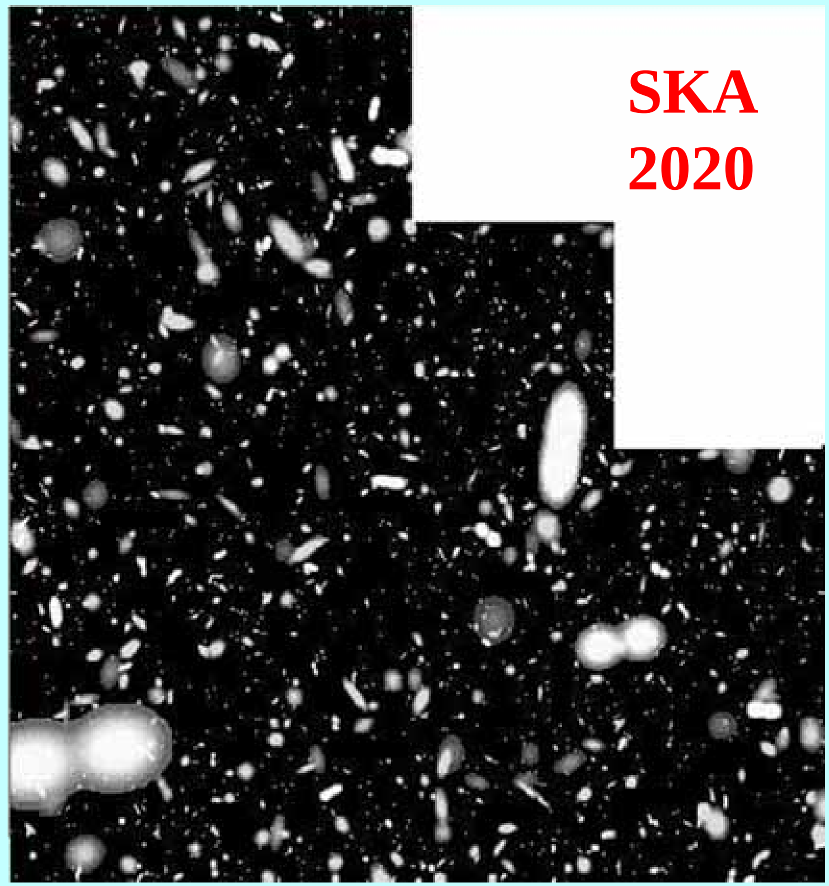
# Key Technical Specifications

- **collecting area** of order 1 million square meters, array of ~5000 dishes each ~12 meters in diameter
- **frequency range** 100 MHz – 25 GHz
- **large instantaneous field of view** 1 sq. deg. at 1.4 GHz
- **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.

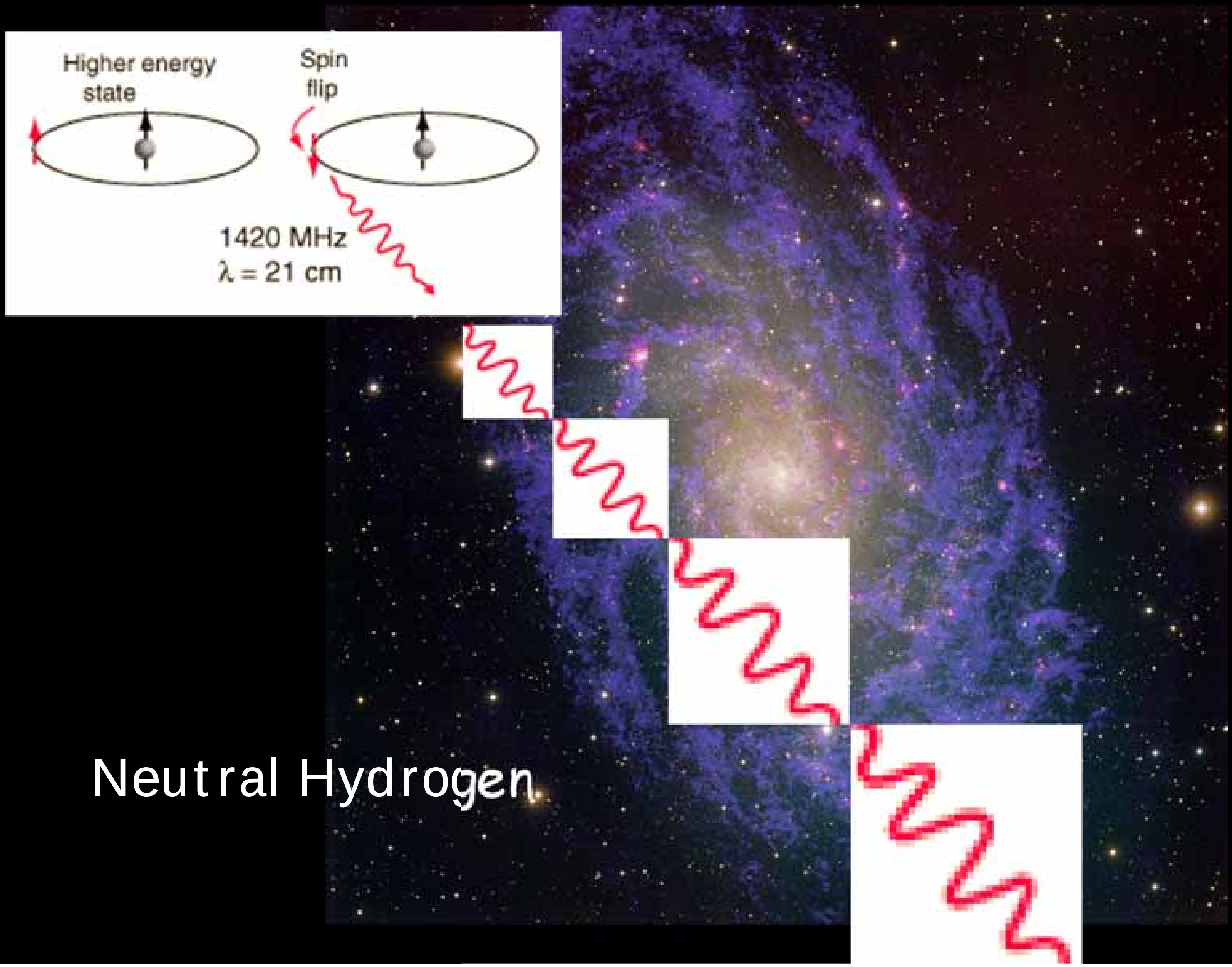

Gravitational
radiation
Adaptive nulling
Big Bang
Evolving
galaxies
Pulsar
First
astronomical
objects
SETI
Gamma-ray
burster
Probing the early Universe
Adaptive nulling

# Future Sensitivity



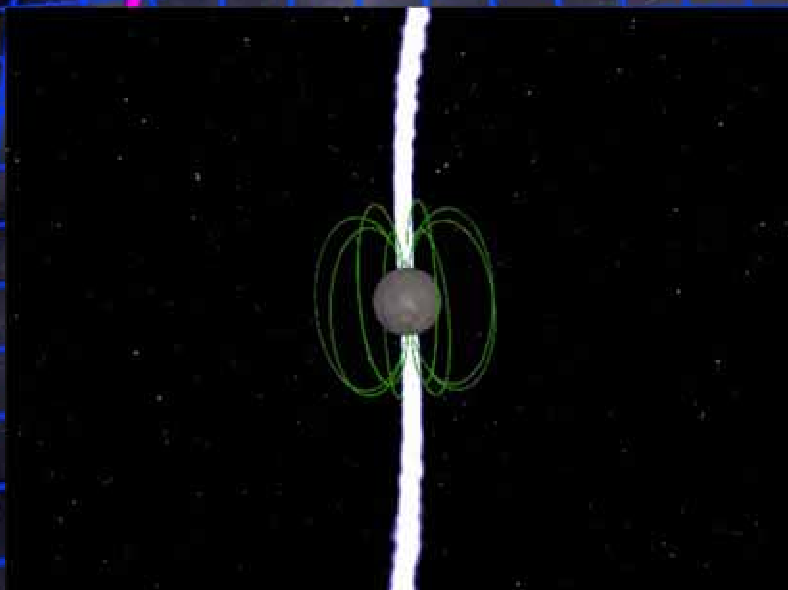



# Radio provides unique information about the Universe




Neutral Hydrogen

# Was Einstein Right?

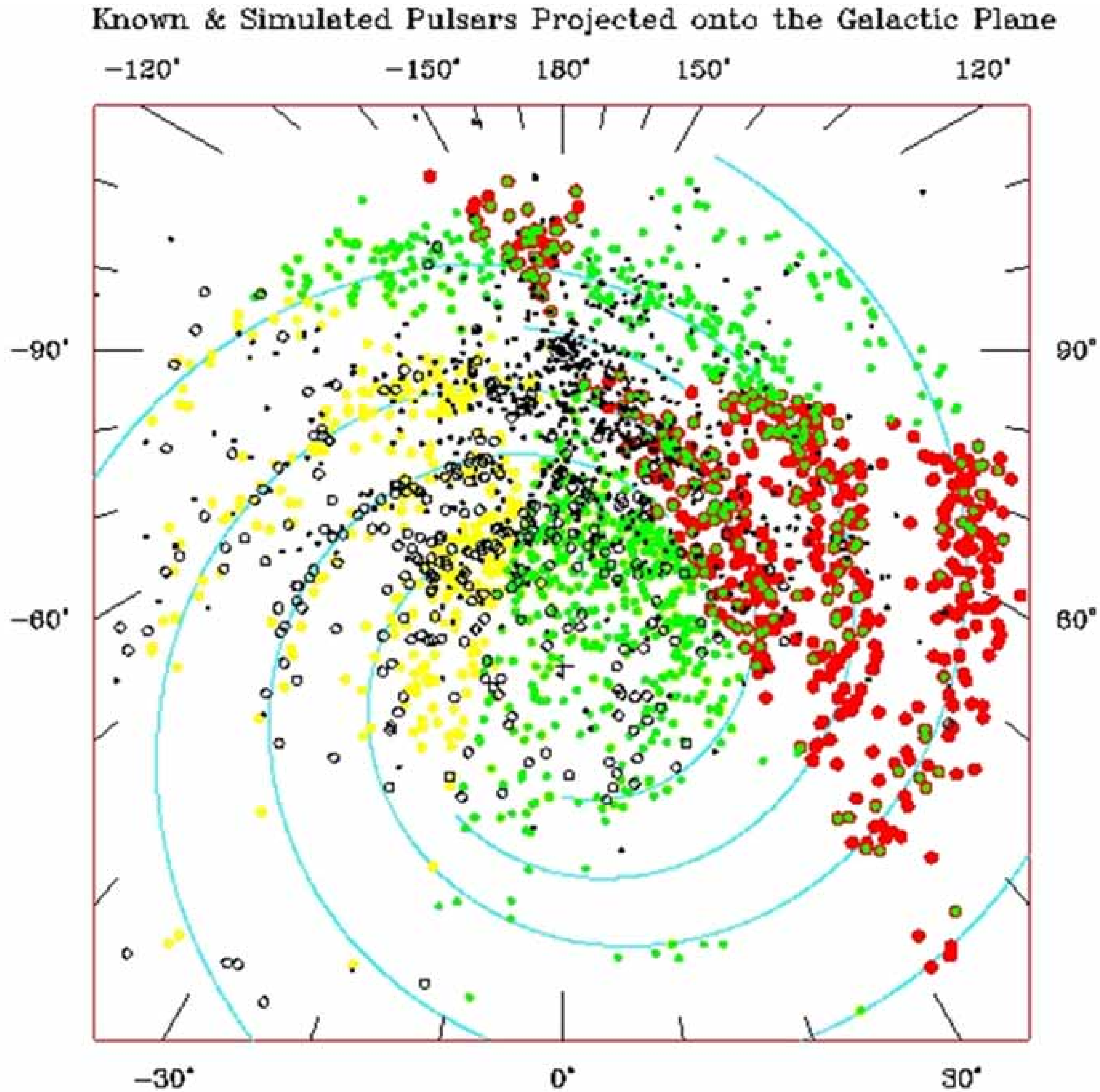


Pulsars: Cosmic Lighthouses

<u>Pulsars</u>

Collapsed stars with extreme physical properties

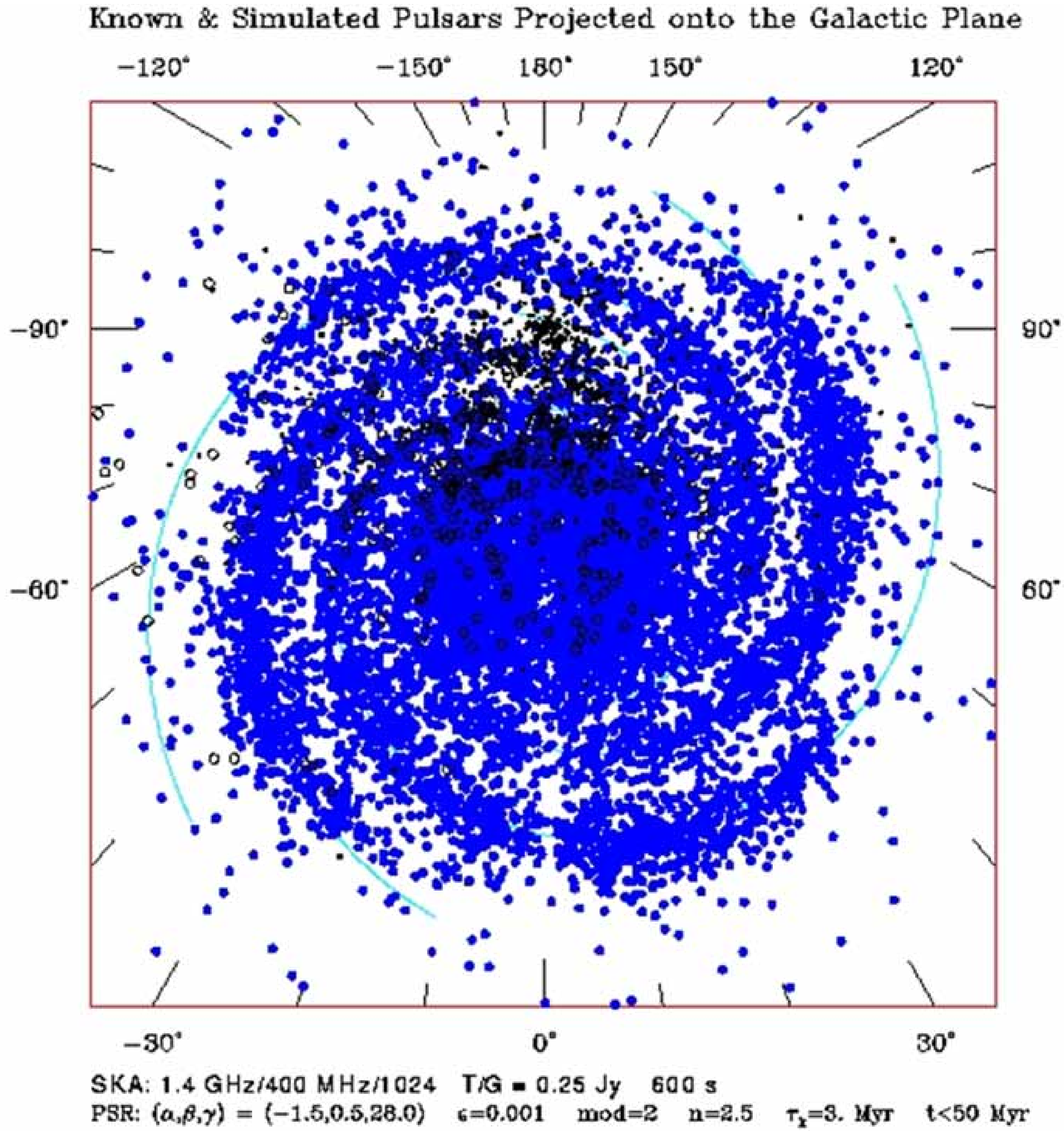
| High Gravity Field | Most accurate clocks known |
| --- | --- |
| 200000xSun | $10^{-9}$sec |




Surveys with Parkes, Arecibo & GBT.

Simulated & actual pulsars shown

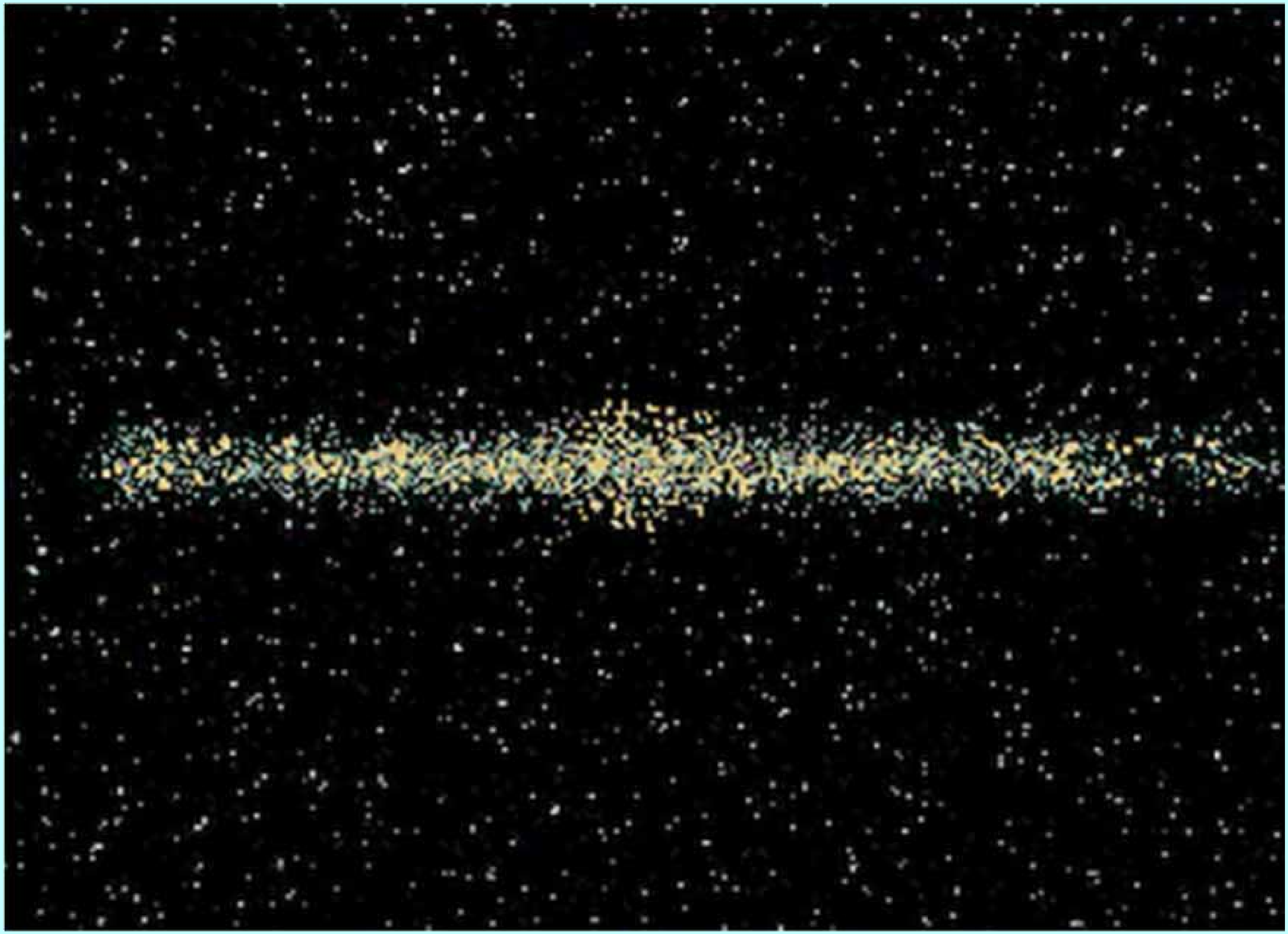
Yield ~ 1000 pulsars in ALFA survey




SKA pulsar survey

600 s per beam

~$10^4$ psr's



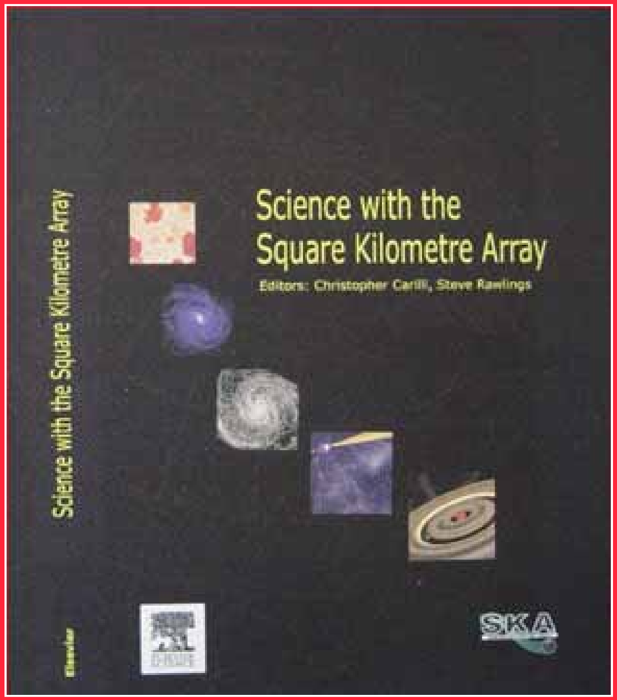
# The Cradle of Life

- Test conditions for life elsewhere in the Universe
  - Image proto-planetary disks
  - Search for Extraterrestial intelligence

***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!***

# SKA science book



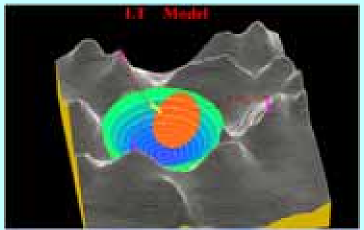

*Science with the*
*Square Kilometre Array,*

eds: C.Carilli, S.Rawlings,

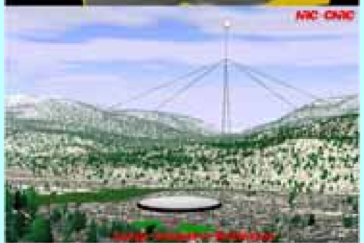
New Astronomy Reviews, Vol.48, Elsevier, Dec. 2004

www.skatelescope.org

# Concepts



**China KARST**



**Canadian aerostat**

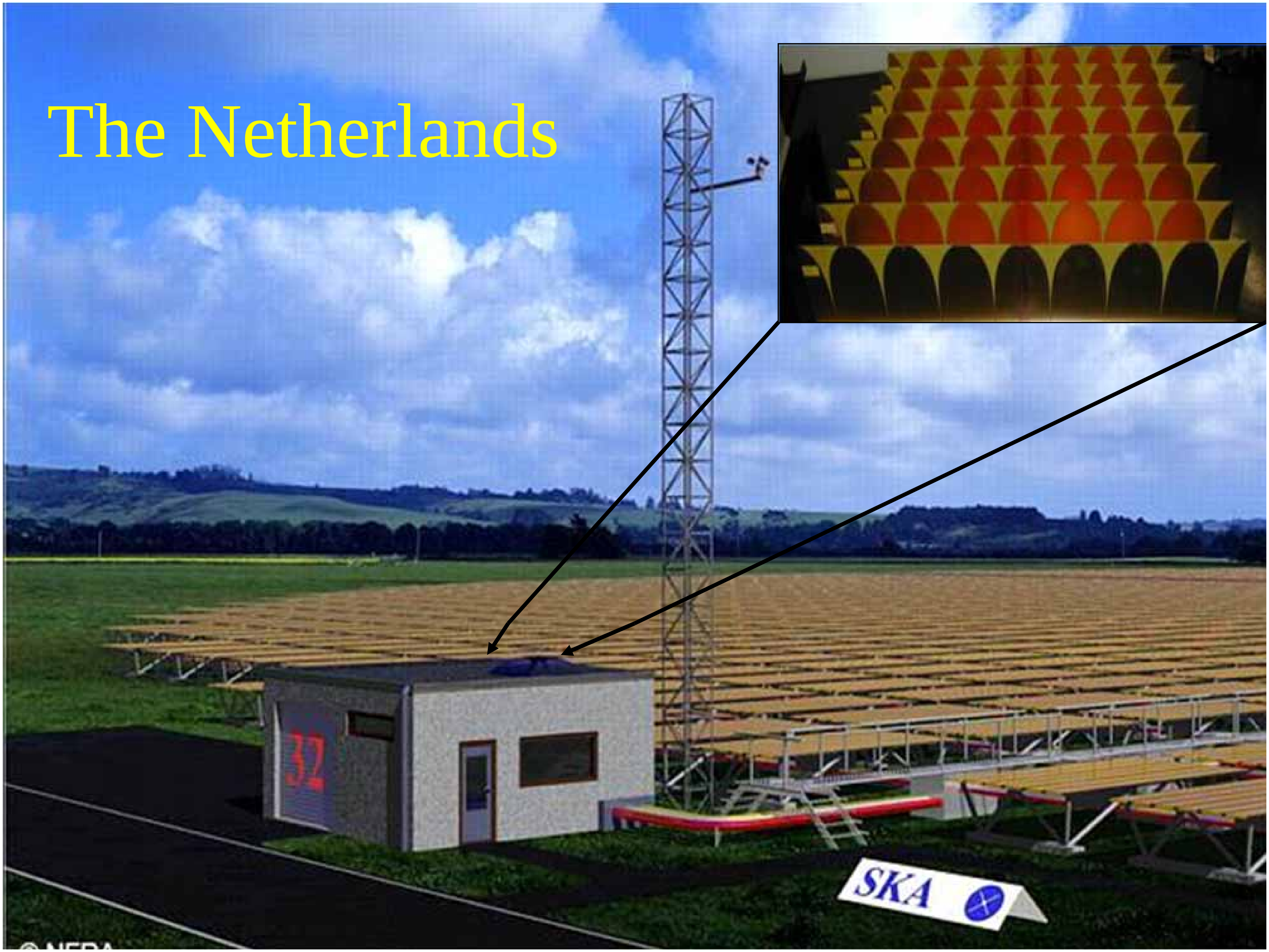
**US Large N**

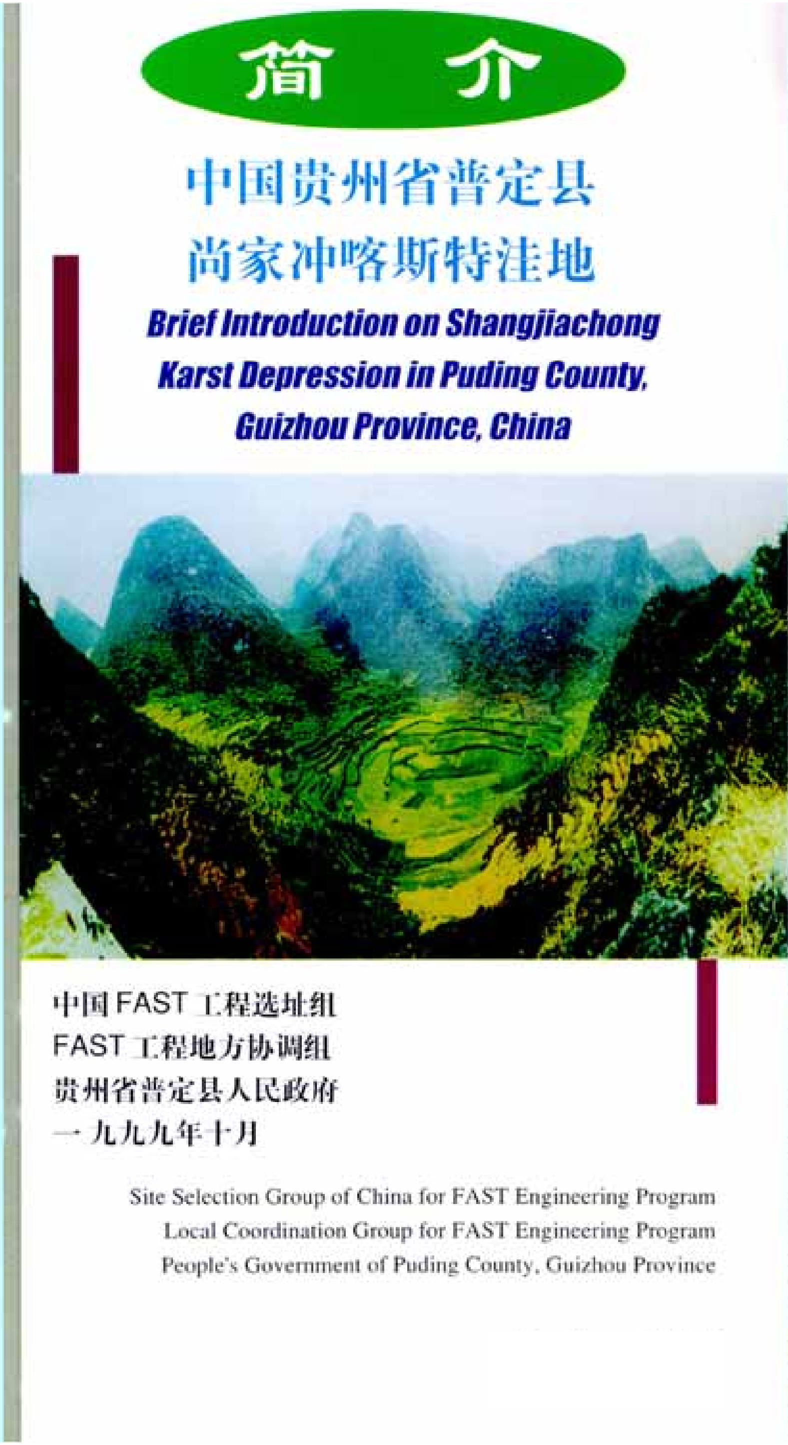
**Antenna designs: India, US.**

**Australia:**
**Luneburg Lenses and Cylinders**

**Dutch Fixed**
**Planar Arrays**

# The Netherlands






# NxArecibo

Karst region for array of large Arecibo-like Telescopes

D > 200 m

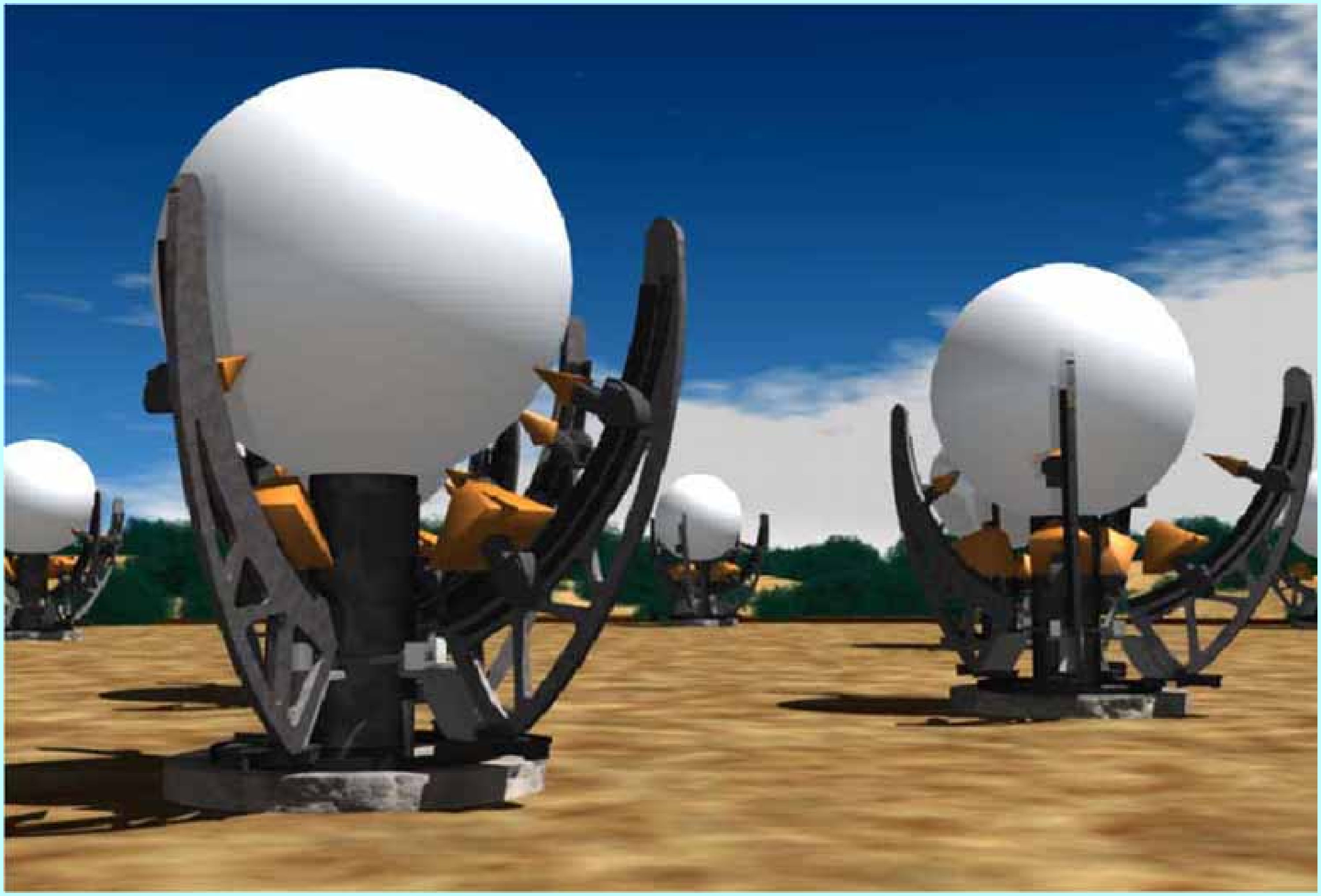
# LAR Prototyping

Instrument Package


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

# Australia

# Multiple Feeds And Beams



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

# U.S. Consortium Concept Synthesis Array

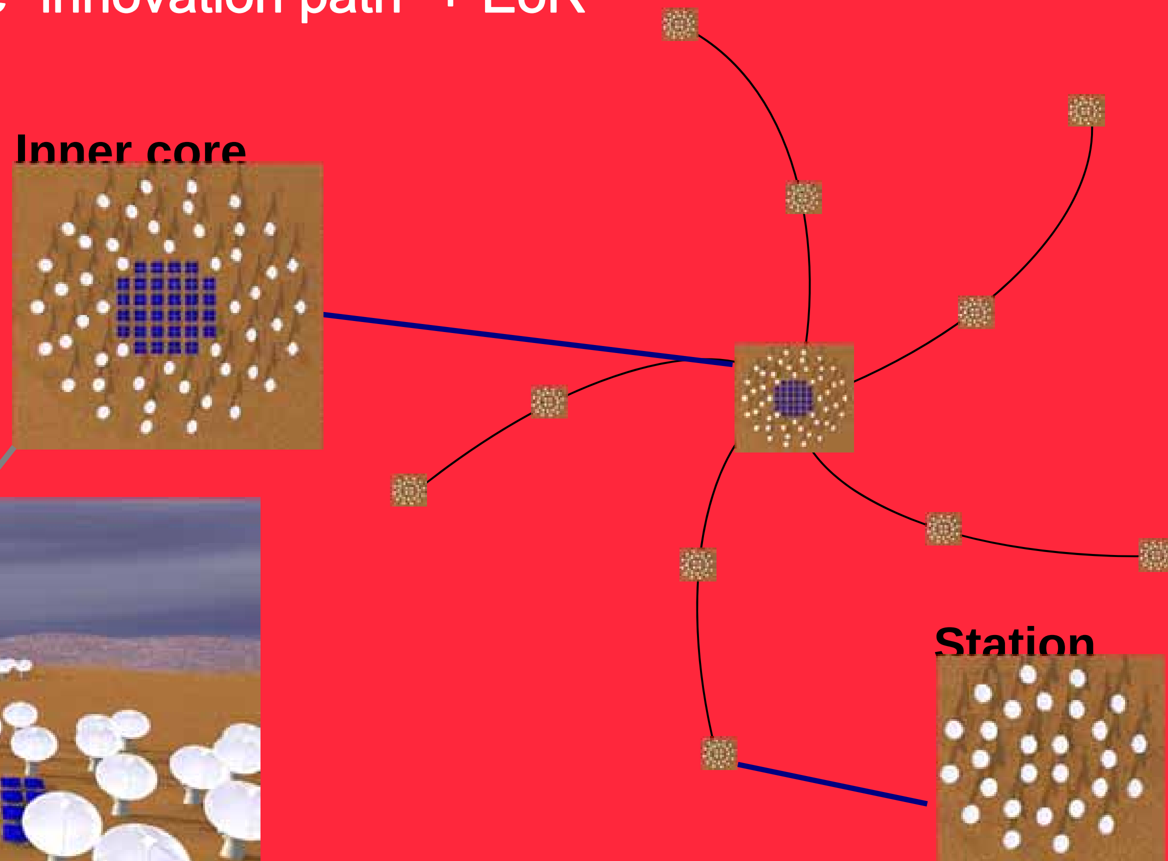
## Large N/Small D

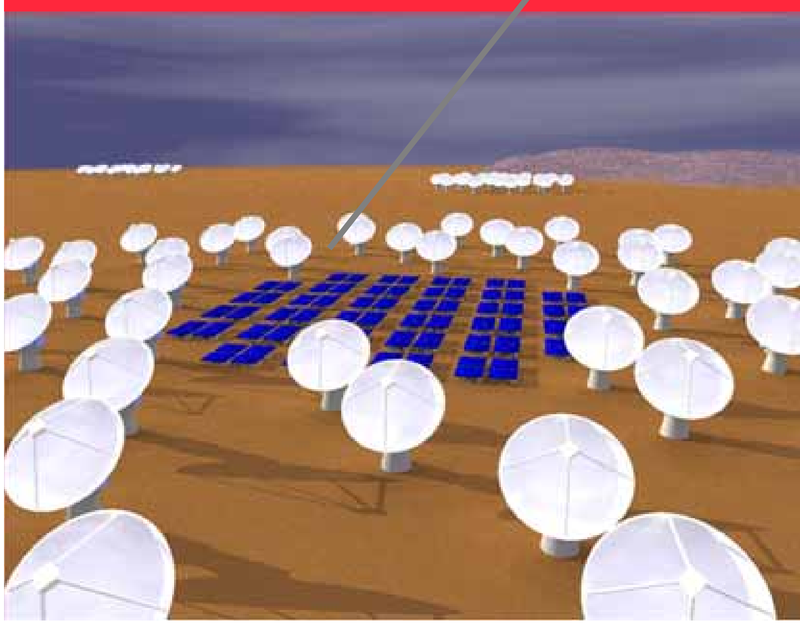
Why large N?
- collecting area
- dynamic range
- baseline diversity
- snapshot mode
- self-calibration
- RFI excision

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

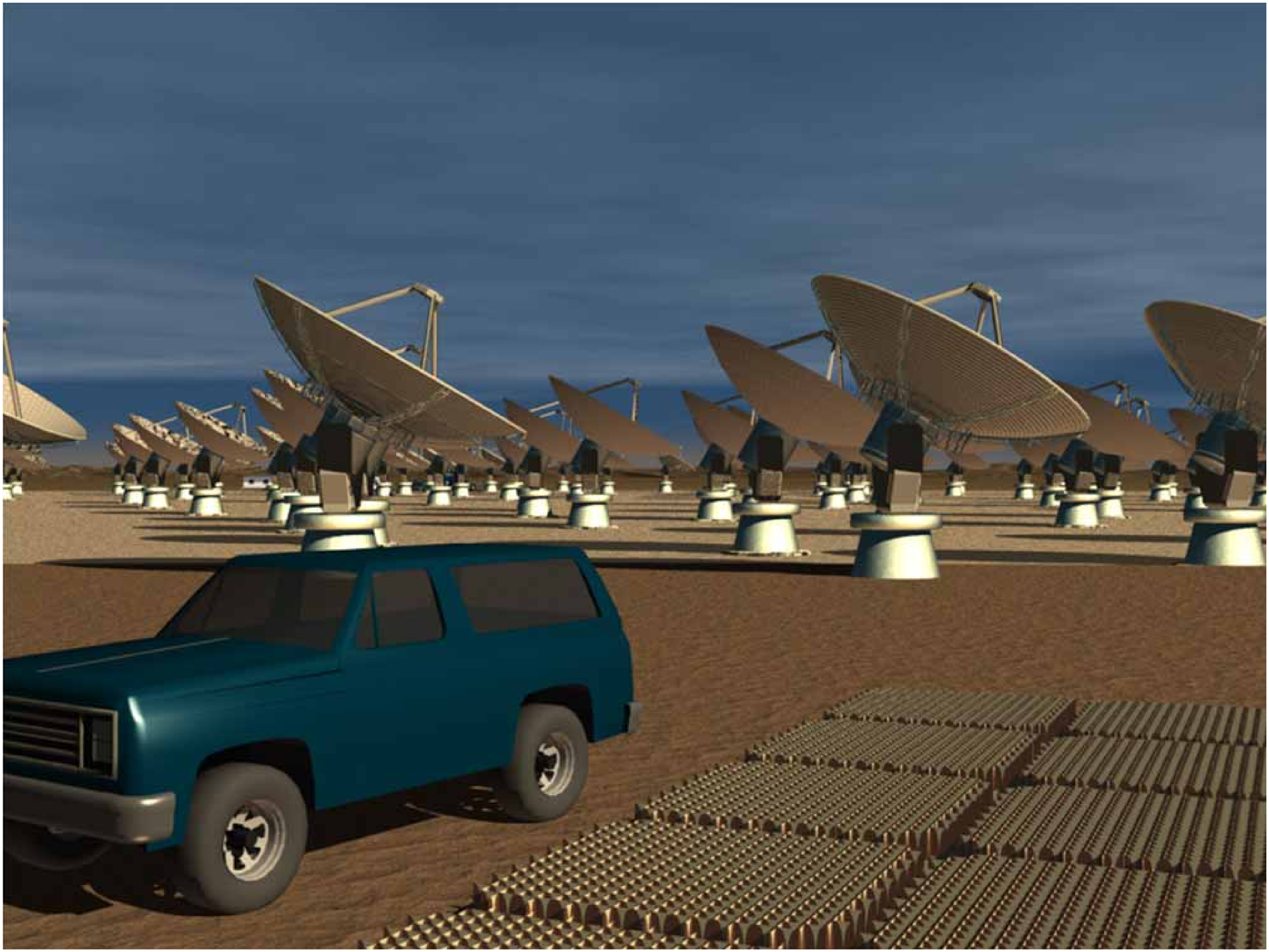
# Reference Design

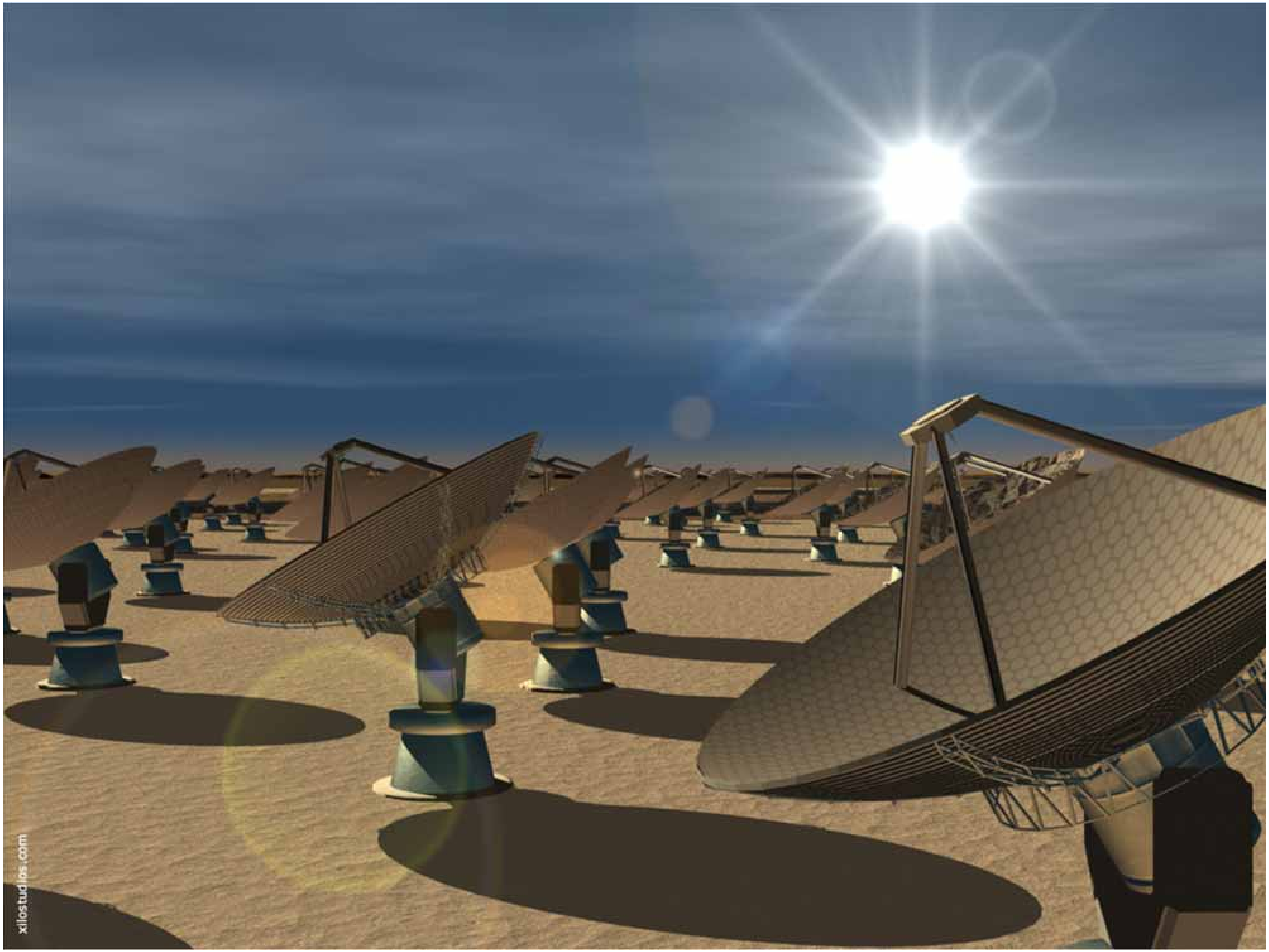
small dishes+smart feeds +
aperture arrays on the "innovation path" + EoR array (0.1-0.3 GHz)



Wide-angle radio camera + radio "fish-eye lens"



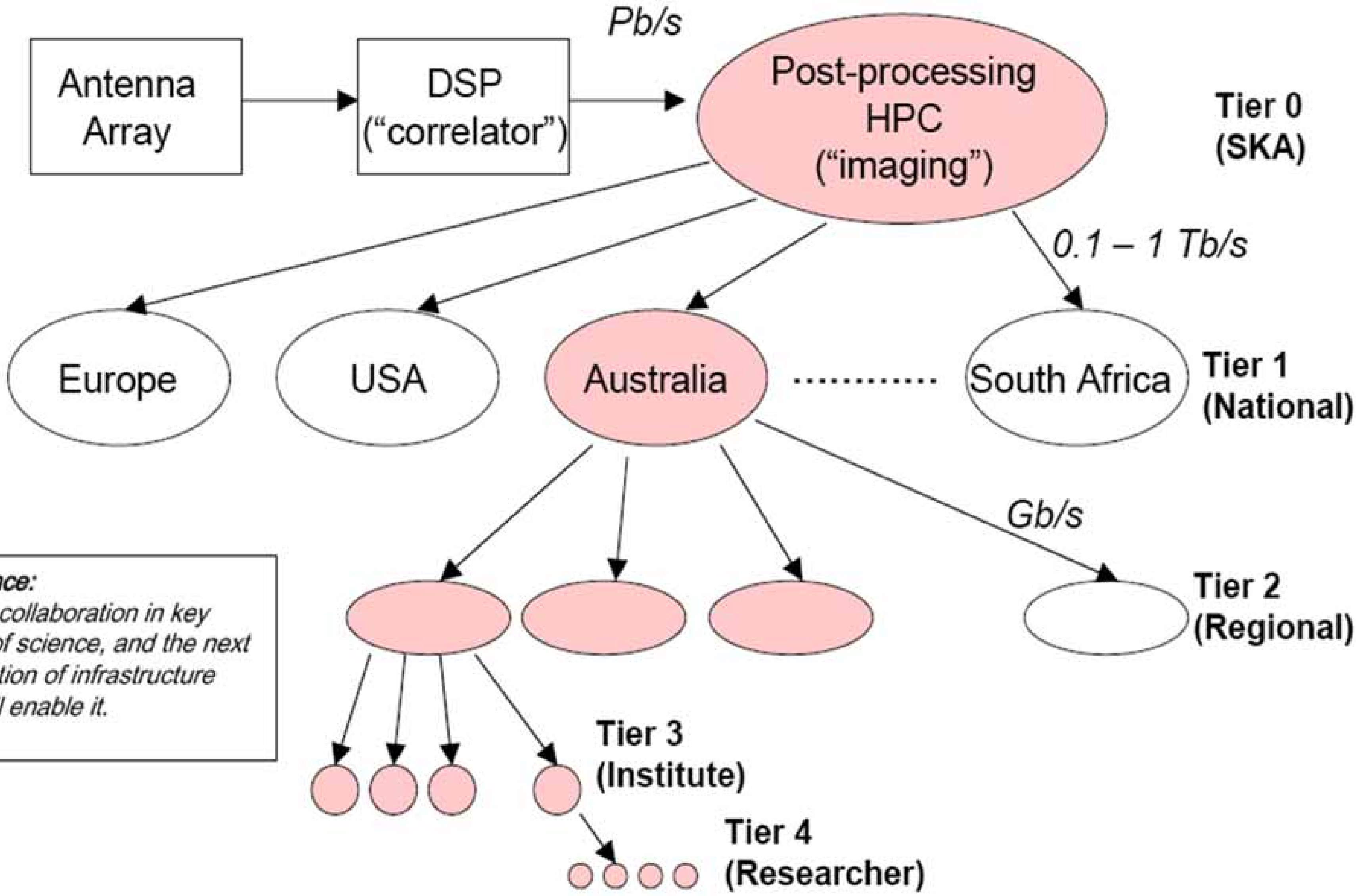

xilostudios.com

# SKA – not just antennas



- High speed data transport
  - Tb/s from EACH station on scales of hundreds of km
  - 100 Gb/s trans-continental and trans-oceanic links
  - Longest links will rely on telcos and research networks
    - » Need government initiatives for affordable access
- Signal processing
  - Peta-ops per second
  - Need highly scaleable solutions
- Post-processing, information management
  - New super-computer architectures
  - Archive and sharing of data will be a major challenge
- Infrastructure
  - Civil, electrical (power, …), communications
- Operations and support

# SKA as e-science




*E-science:*
*Global collaboration in key areas of science, and the next generation of infrastructure that will enable it.*

# GOVERNANCE

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

# International SKA Steering Committee (ISSC to SSEC )

**21 members representing 11 countries**

–7 European (2 UK, France, Germany, 2 Netherlands, Italy)

–7 United States

–2 Canada

–2 Australia

–2 Asia (China, India)

–1 South Africa

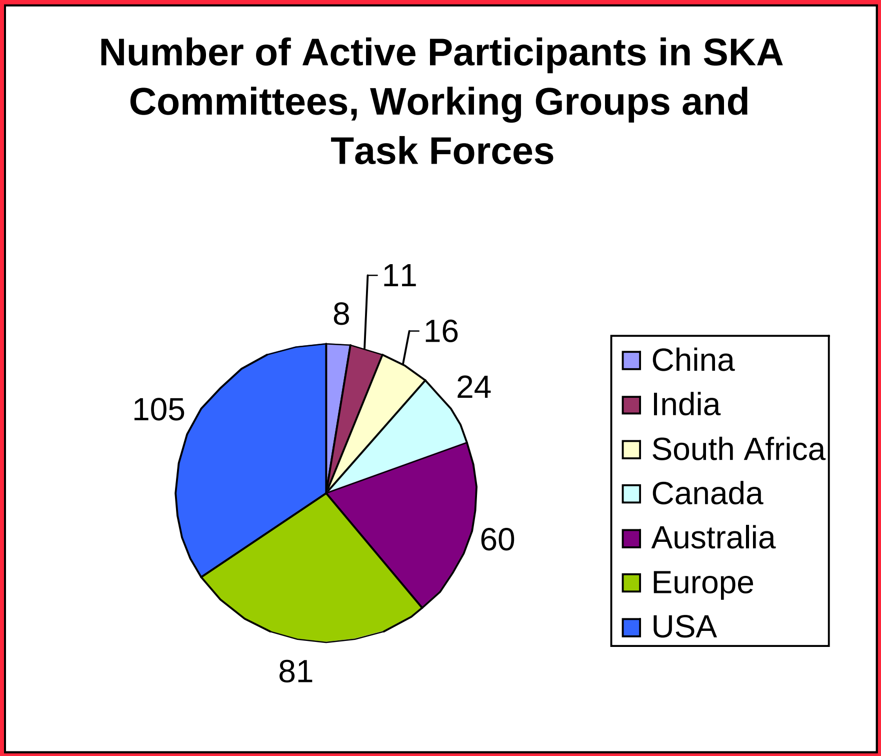
–Observers from Japan, Russia

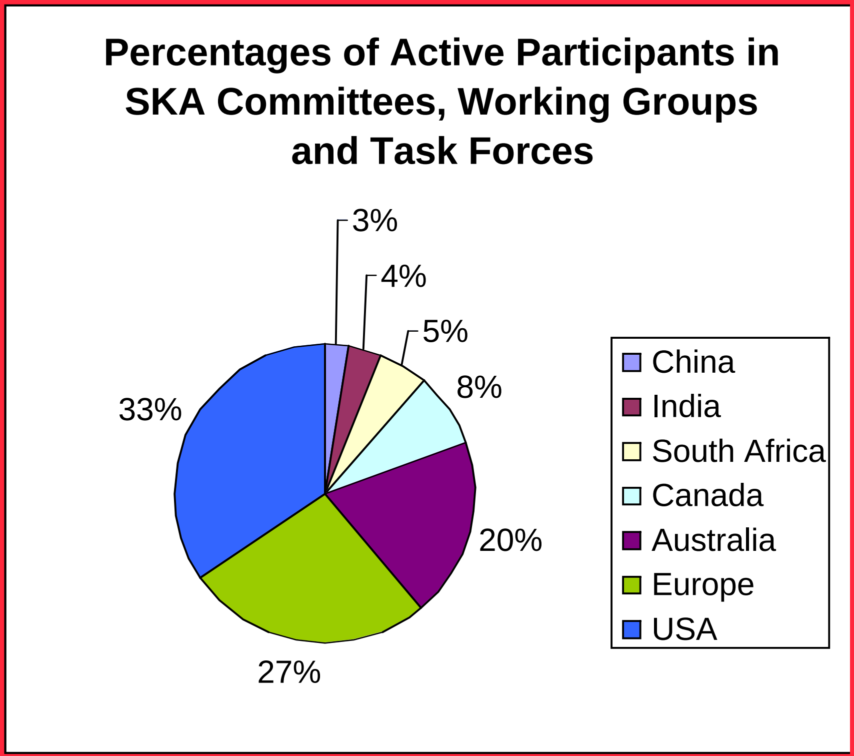
# SKA: How much will it cost?

| | |
|---|---|
| 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%


Number of Active Participants in SKA Committees, Working Groups and Task Forces
8
11
16
24
60
81
105
China
India
South Africa
Canada
Australia
Europe
USA


Percentages of Active Participants in SKA Committees, Working Groups and Task Forces
3%
4%
5%
8%
20%
27%
33%
China
India
South Africa
Canada
Australia
Europe
USA

# Where will the SKA be built?

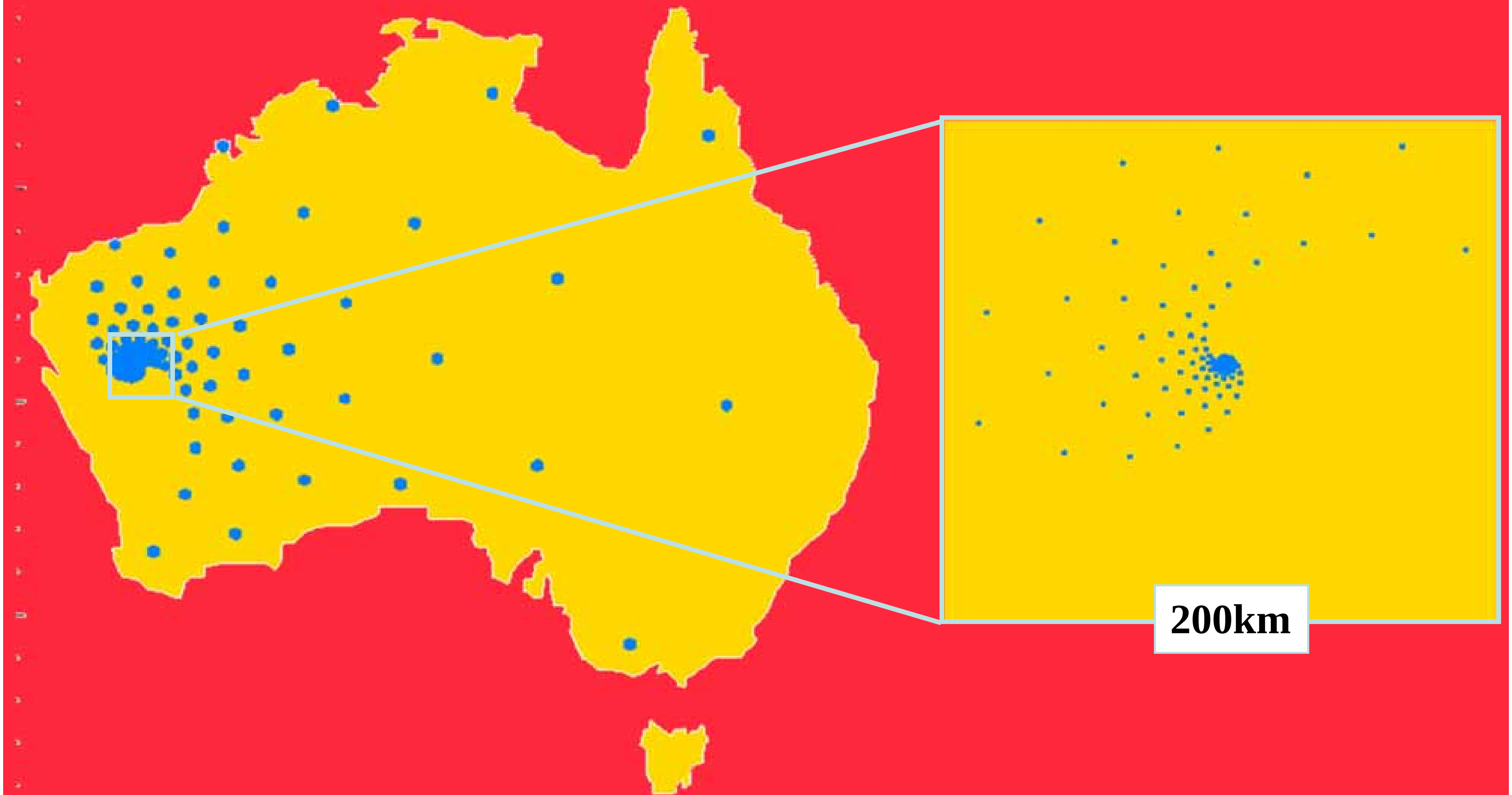
- Northern (infrastructure) vs Southern (Galactic Center) hemisphere
- RFI environment
- Troposphere stability (high desert site)
- Ionospheric stability
- Political issues
- Preliminary proposals
  - U.S., Australia, South Africa, Argentina, Brazil, China
- Decision - Oct. 2006 (short list of acceptable sites)

# ISSC SHORT LISTED CORE SITES

SOUTH AFRICA

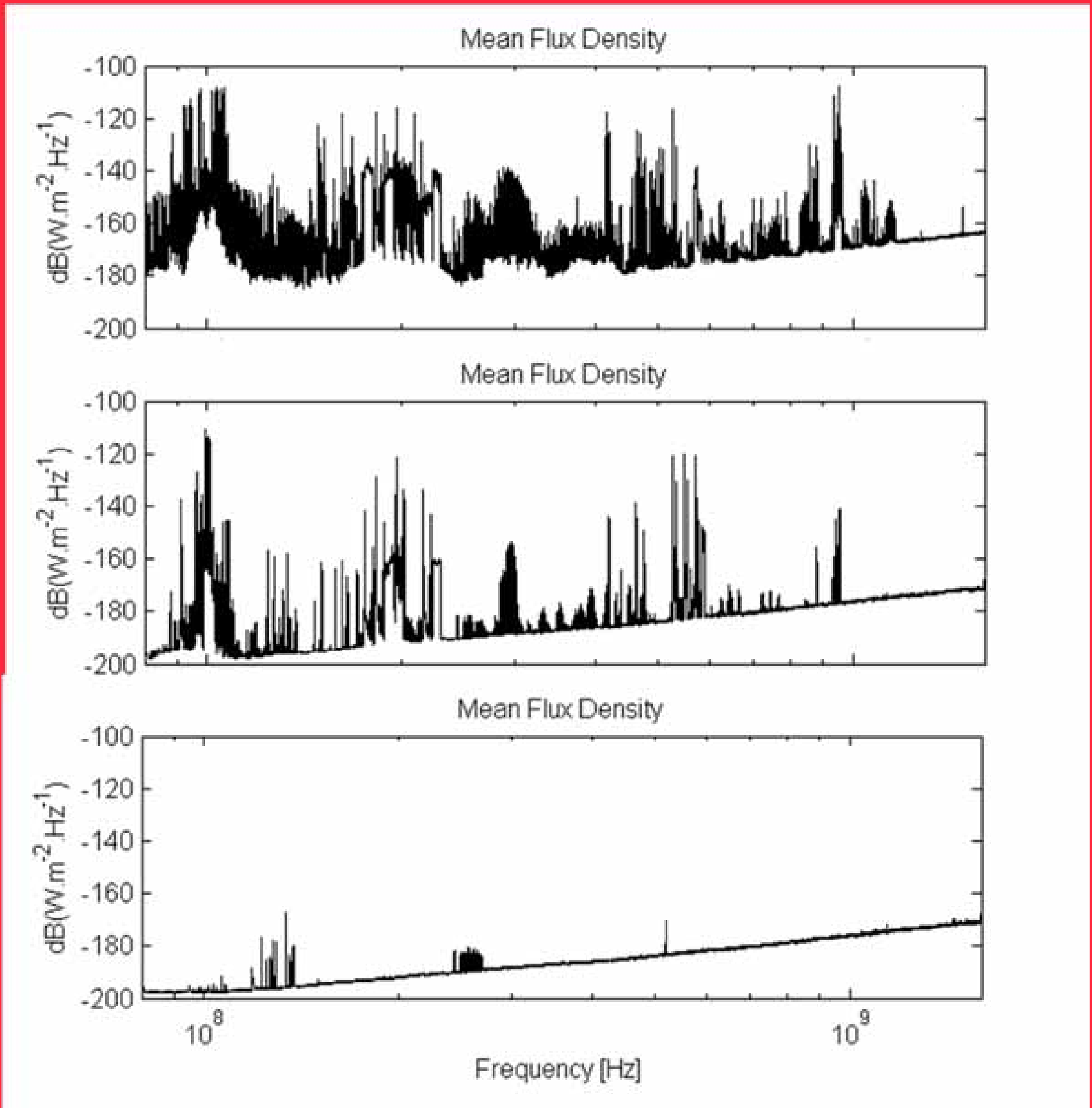
AUSTRALIA

# SKA configuration
# Western Australia example



# Australia

# Site selection

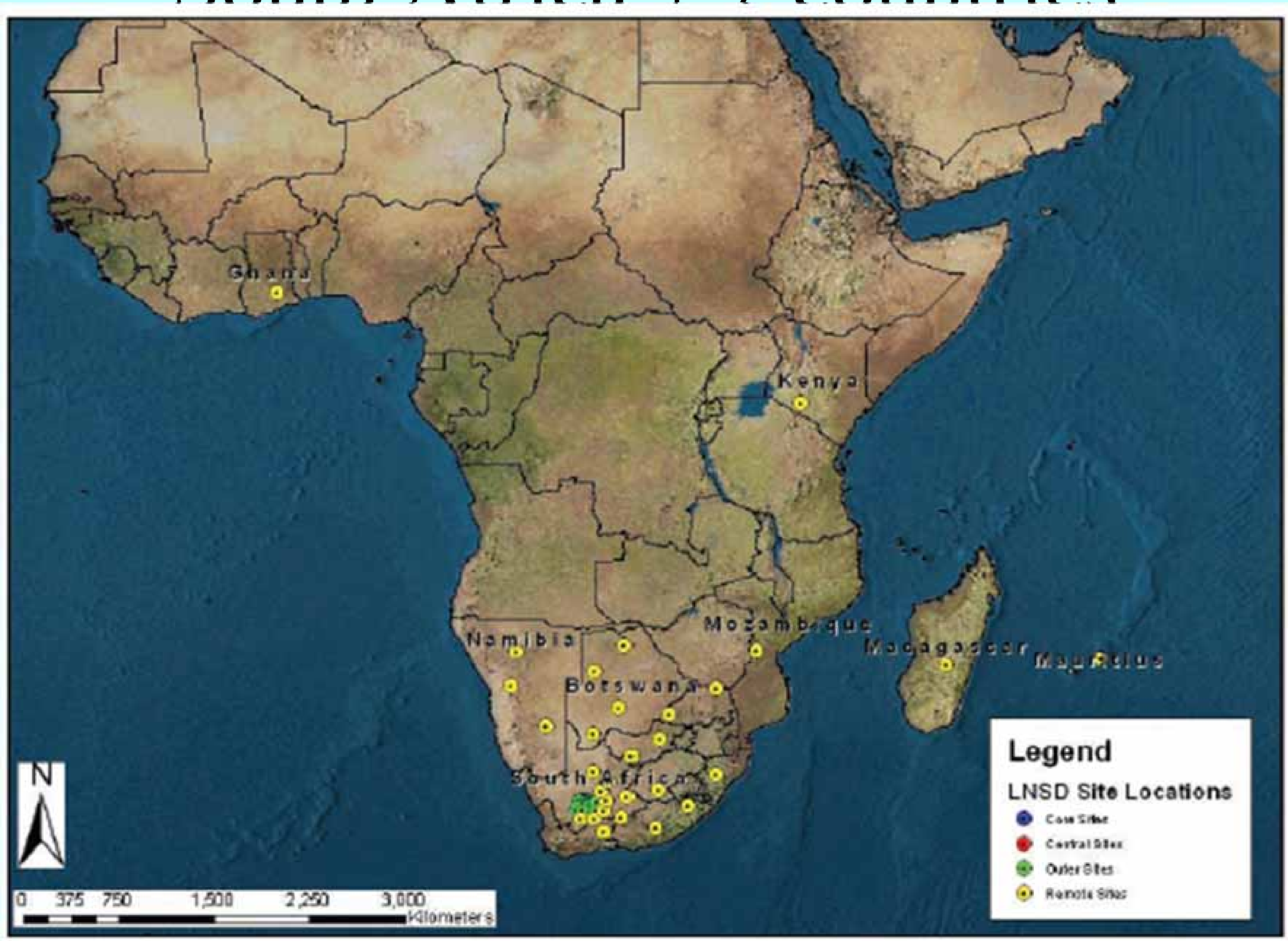



Sydney:
population 4 million

Narrabri:
population 4000

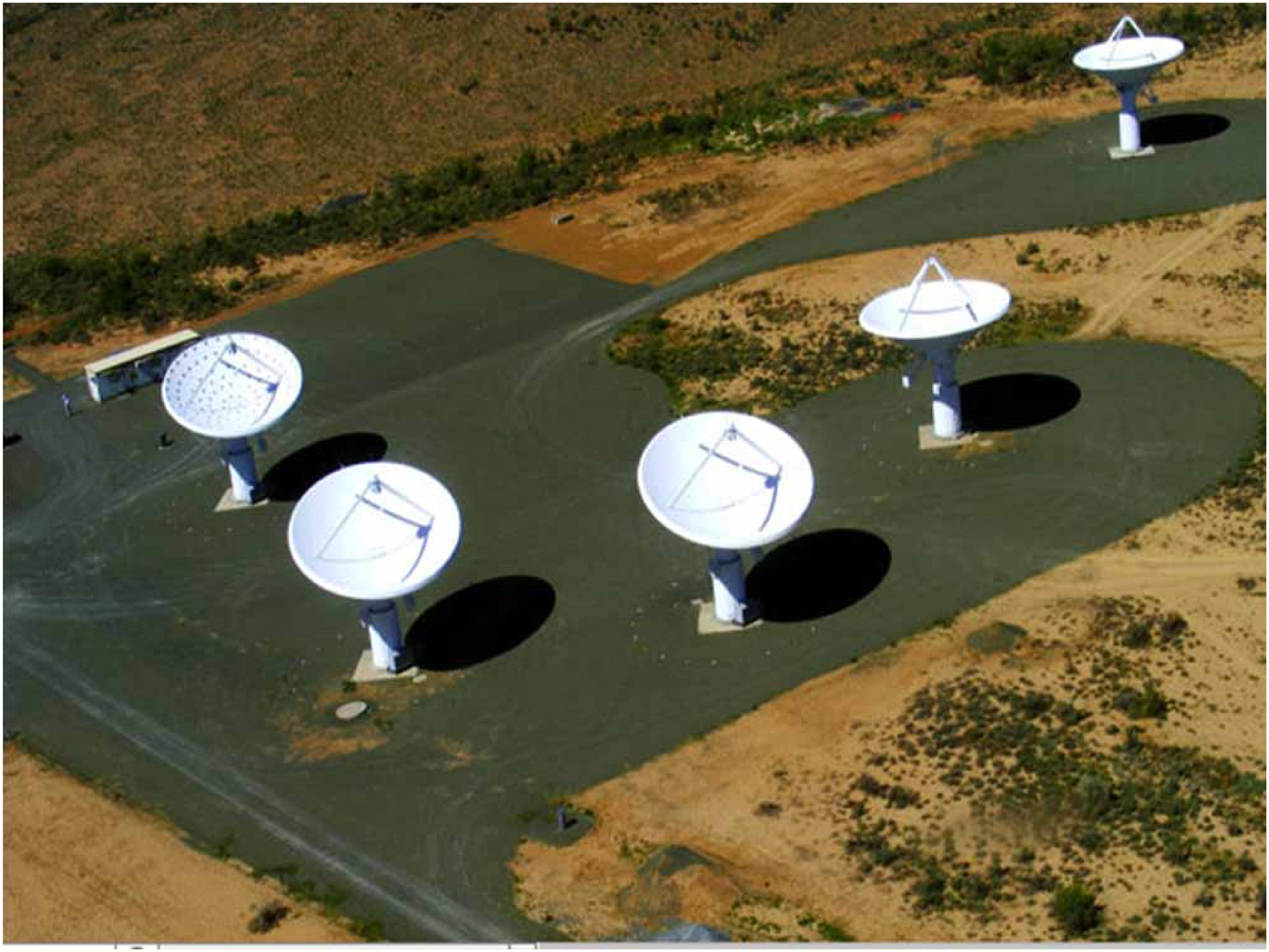
Mileura:
population 4

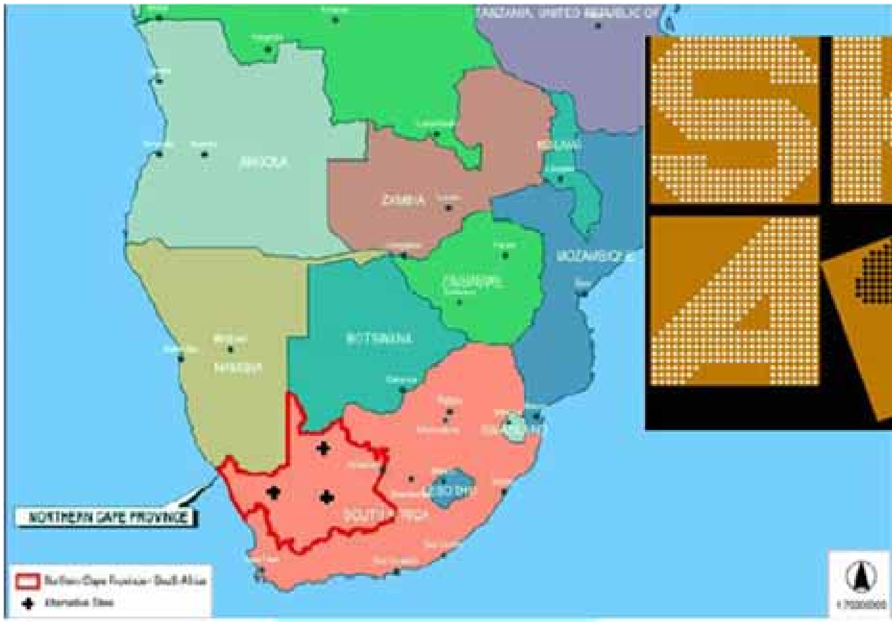
# South Africa + 7 countries

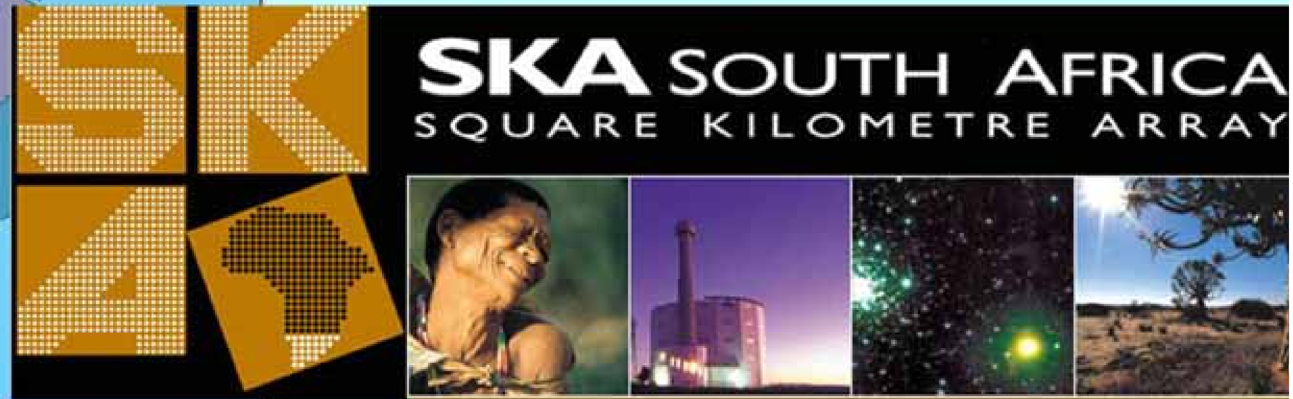


South Africa

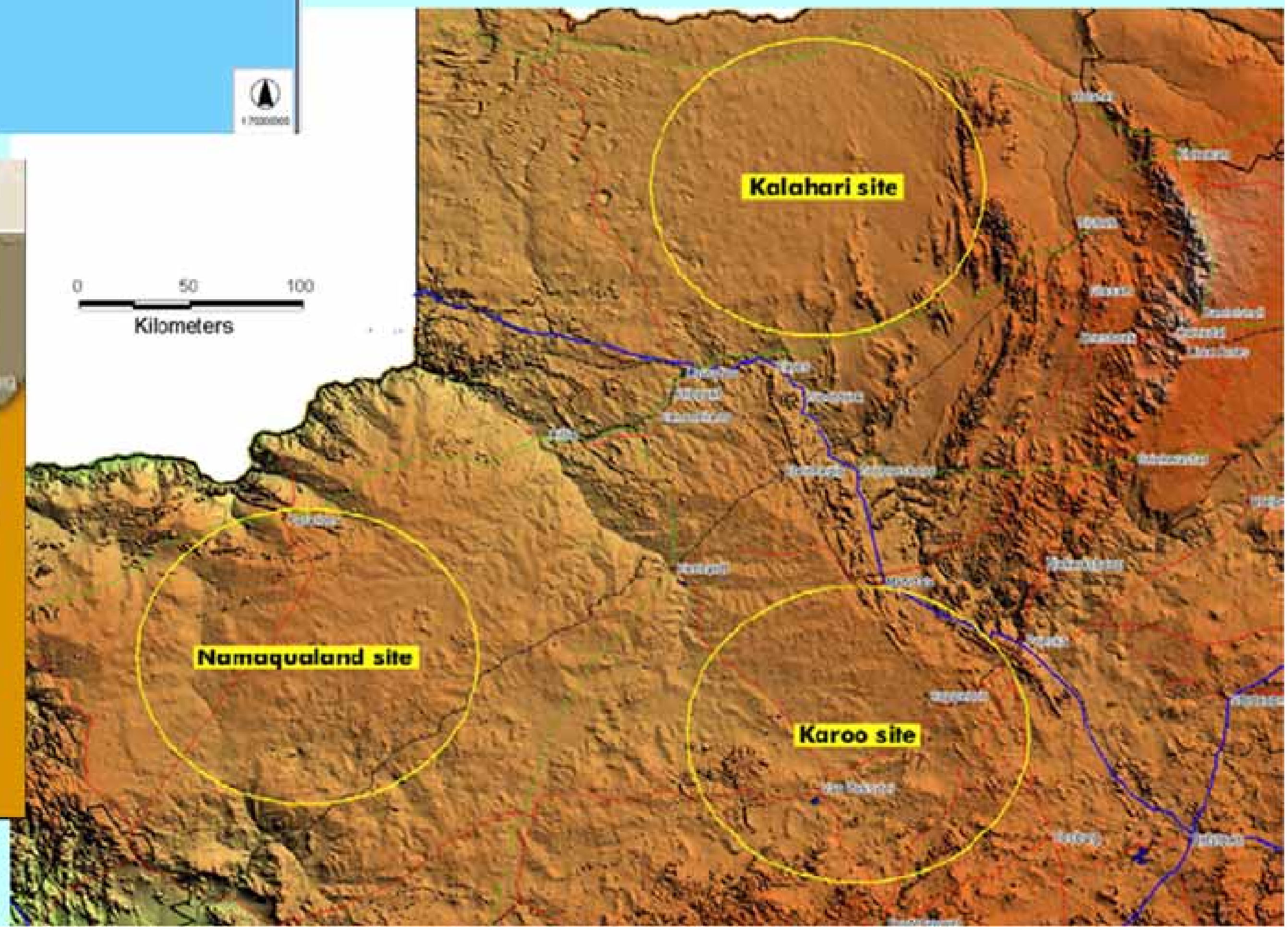
# RFI Measurements

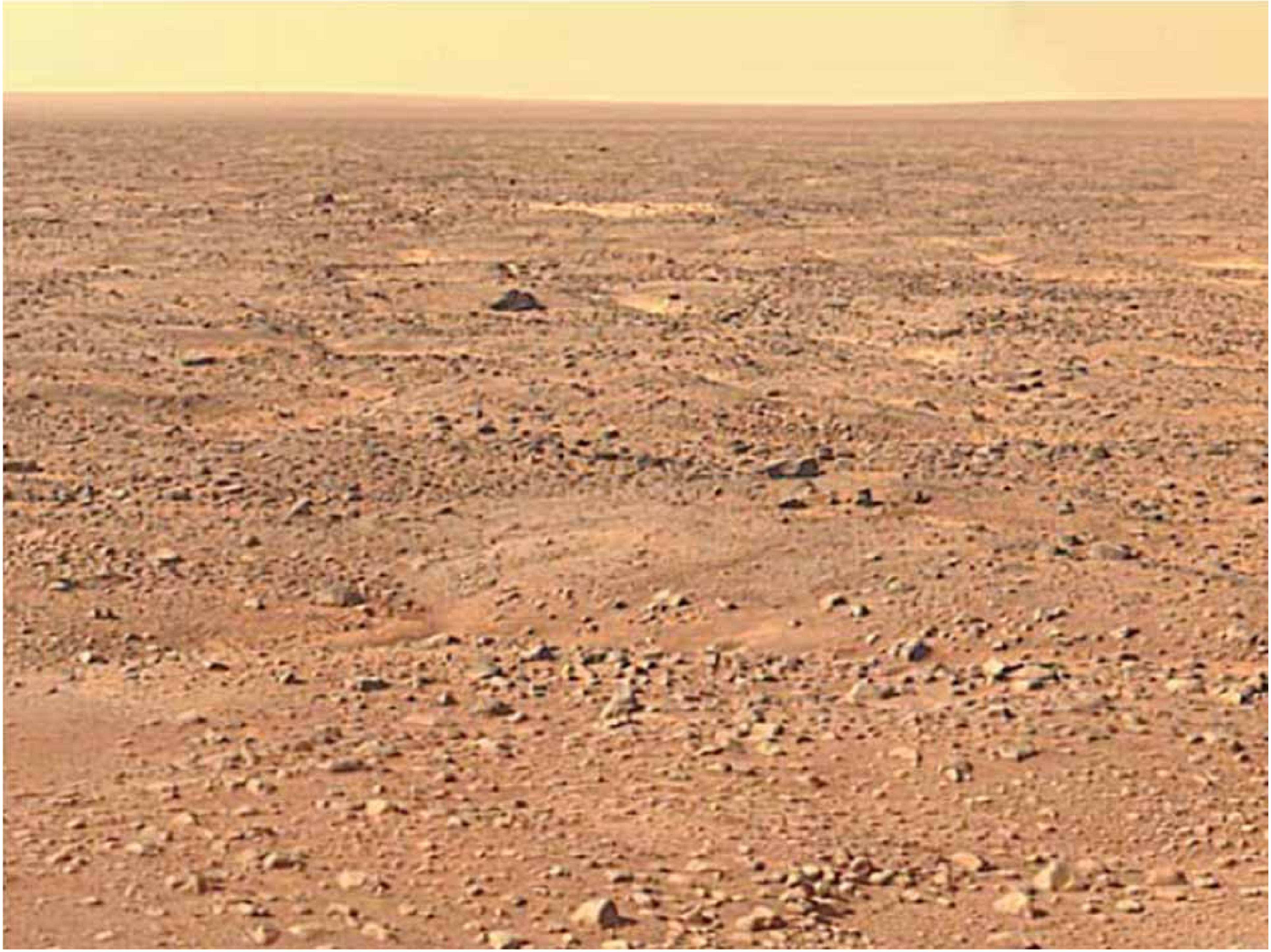



ANGOLA
ZAMBIA
BOTSWANA
NORTHERN CAPE PROVINCE


SKA SOUTH AFRICA
SQUARE KILOMETRE ARRAY


Log spiral array map for the Namaqualand Site
ANGOLA
ZAMBIA
MALAWI
BOTSWANA
NAMIBIA
SOUTH AFRICA


0
50
100
Kilometers
Kalahari site
Namaqualand site
Karoo site



# NATIONAL ATTRIBUTES

- Political and economic structure and stability
- Entry visas to all
- Ease of government interactions
- Import/export issues and taxes
- Access to foreign companies
- Land claims
- General support of science and technology
- Academic astronomy population
- Availability of engineers and technical personnel

# POSSIBLE OUTCOMES

1) Winner takes all

2) Win-Win

SKA-LO in one country
SKA-MID in the other country

Most of the SKA in one country
A mega-station in the other country

Dishes in one country
Aperture arrays in the other country
(Some science duplications ??)

NOTE: Cost duplications ? And issues with all Win-Win models.

SKA IN THREE FREQUENCY BANDS

--SKA LOW   100 MHz  TO  300 MHz

--SKA MID  300 MHz TO 10 GHz

--SKA HIGH  10 GHz TO 25-35 GHz

US SKA CONSORTIUM FOUNDED IN 1999

To promote the future of radio astronomy in the US universities and research centers, and to coordinate the SKA activities in the US

# US SKA Consortium

Chair: Yervant Terzian (Cornell)
Vice Chair: Joseph Lazio (NRL)

Caltech/JPL
Cornell/NAIC
Harvard/Smithsonian
MIT/Haystack
NRAO
NRL

SETI Institute
University of Illinois
University of New Mexico
University of Wisconsin
UC Berkeley
Virginia Tech

# SKA timeline