Present and Future Radio Instrumentation

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13th June 2008

Gas and Stars in Galaxies, Garching

A time of renewal…

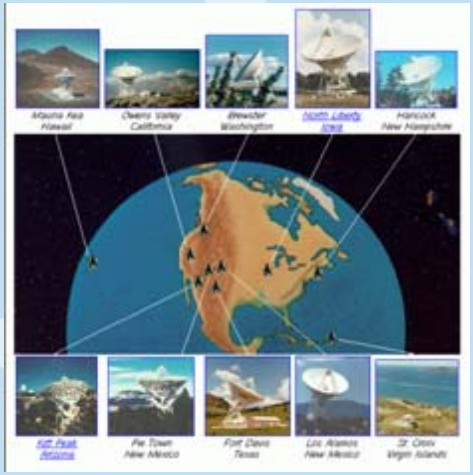
- Radio astronomy is undergoing its 3rd renewal:
  - #1: 1933 – 1960, invention of the technique, suspended during WWII, radar scientists around the world came home and established it as a branch of astronomy
  - #2: 1960 – 1990, development of major instruments + aperture synthesis, e.g. Lovell Telescope, Cambridge instruments, Effelsberg 100m, Arecibo, WSRT, VLA, MERLIN, EVN, VLBA…
  - 1990 – 2005: exploitation of major investments. VLA most productive telescope on Earth.
  - #3: 2006 – 2016(?): development of broadband fibre-optic data transmission and highly-capable digital signal processing systems → ALMA, EVLA, e-MERLIN, e-VLBI, phased array systems…..
  - #4? 2016…. SKA

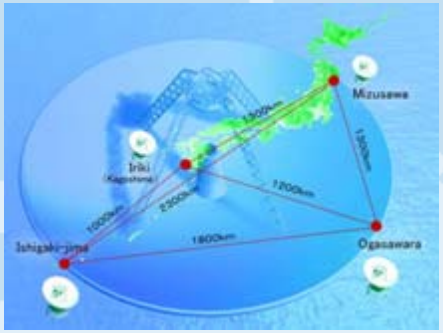
European Radio Astronomy

European Radio Astronomy

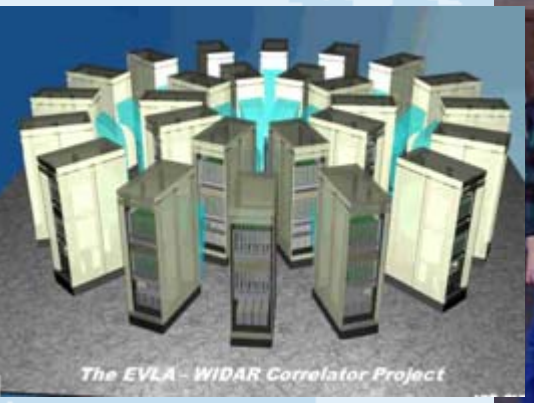
European Radio Astronomy

Elsewhere in the world…





EVLA



Ten Times the Astronomical Capability of the VLA.

- Sensitivity, Frequency Access, Image Fidelity, Spectral Capabilities, Spectral Fidelity, Spatial Resolution, User Access

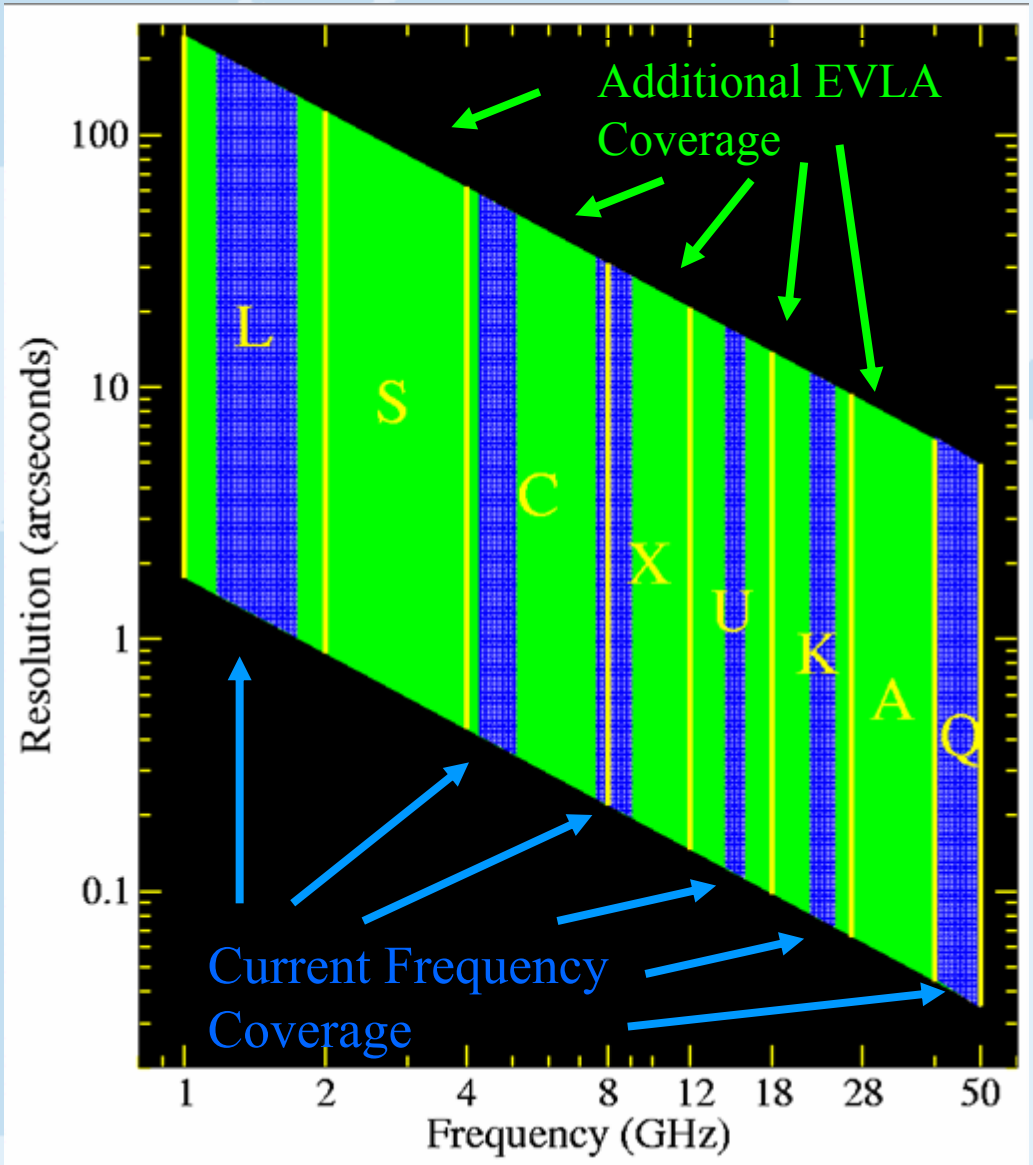
ALMA's centimetre "twin"

Cost: $57M

Complete in 2012, but early science underway now

Frequency - Resolution Coverage

- A key EVLA requirement is continuous frequency coverage from 1 to 50 GHz.
- Blue areas show existing coverage.
- Green areas show new coverage.



Frequency - Resolution Coverage

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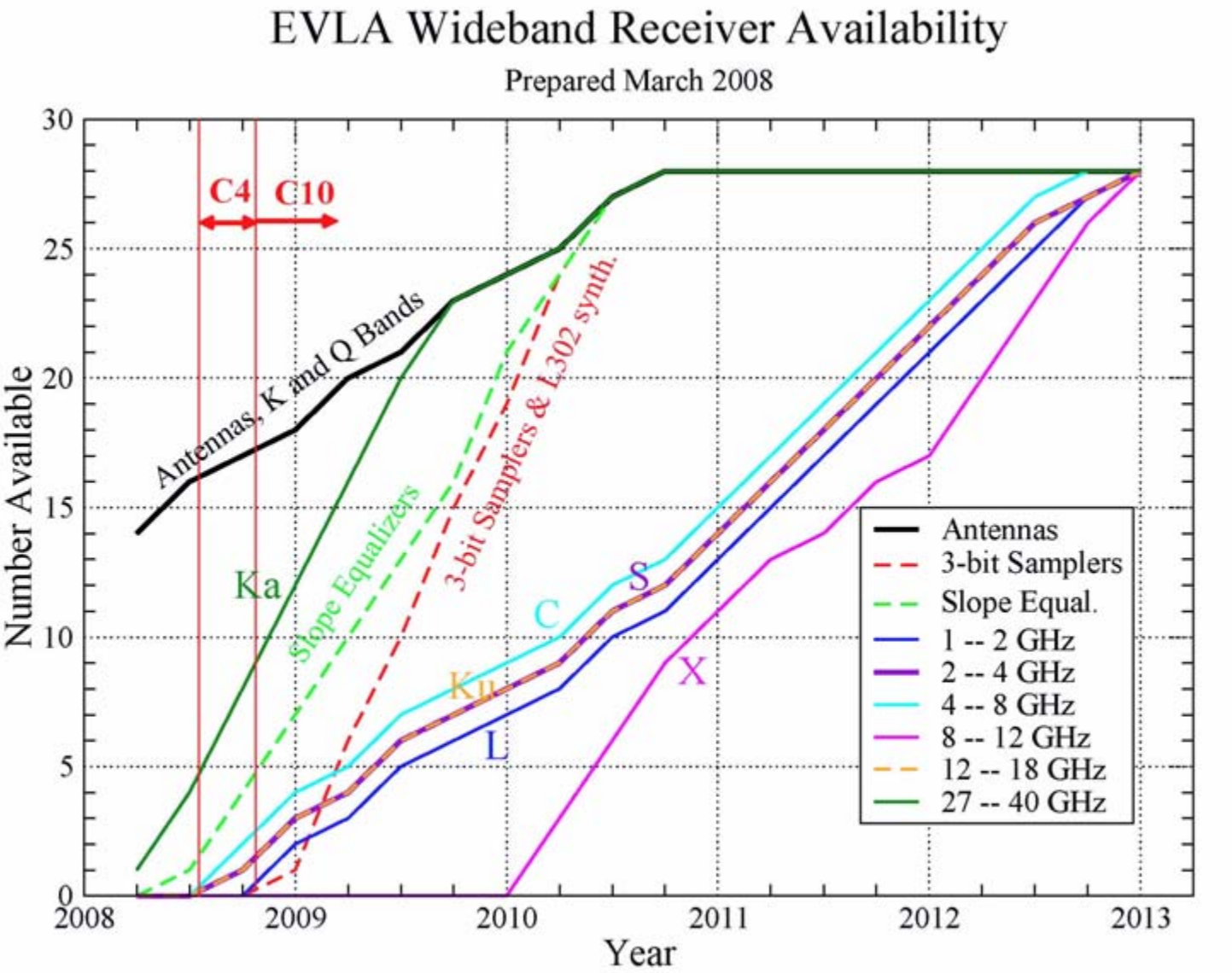
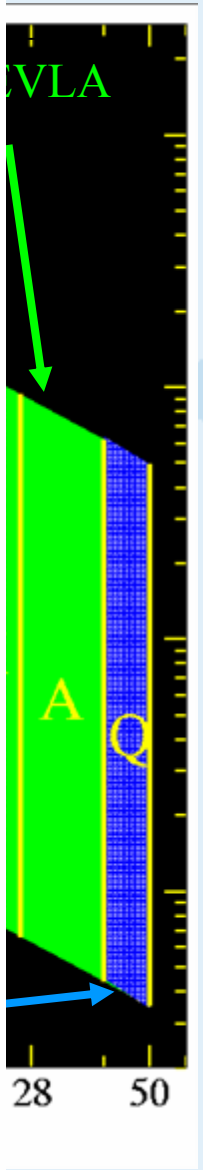
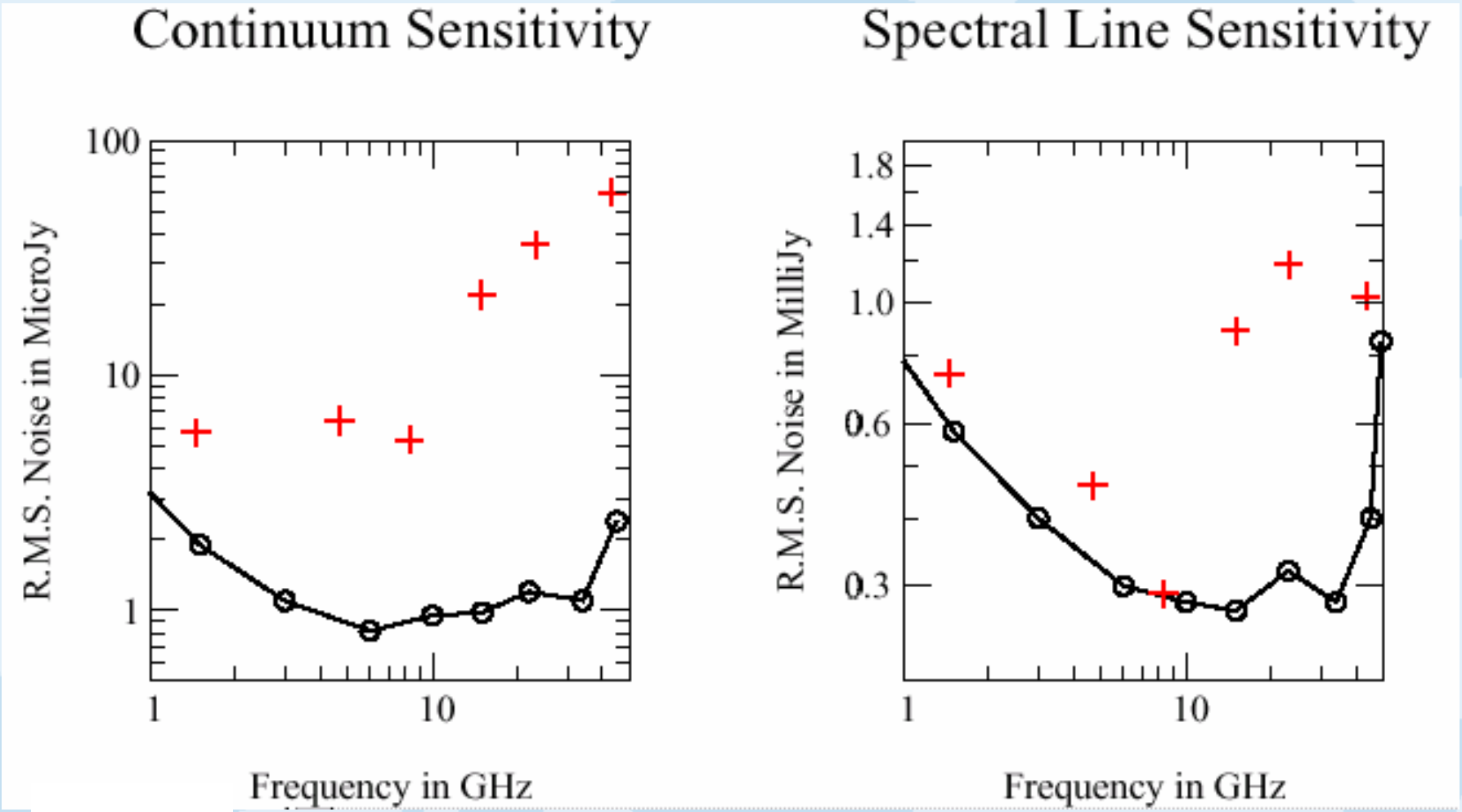
-
-





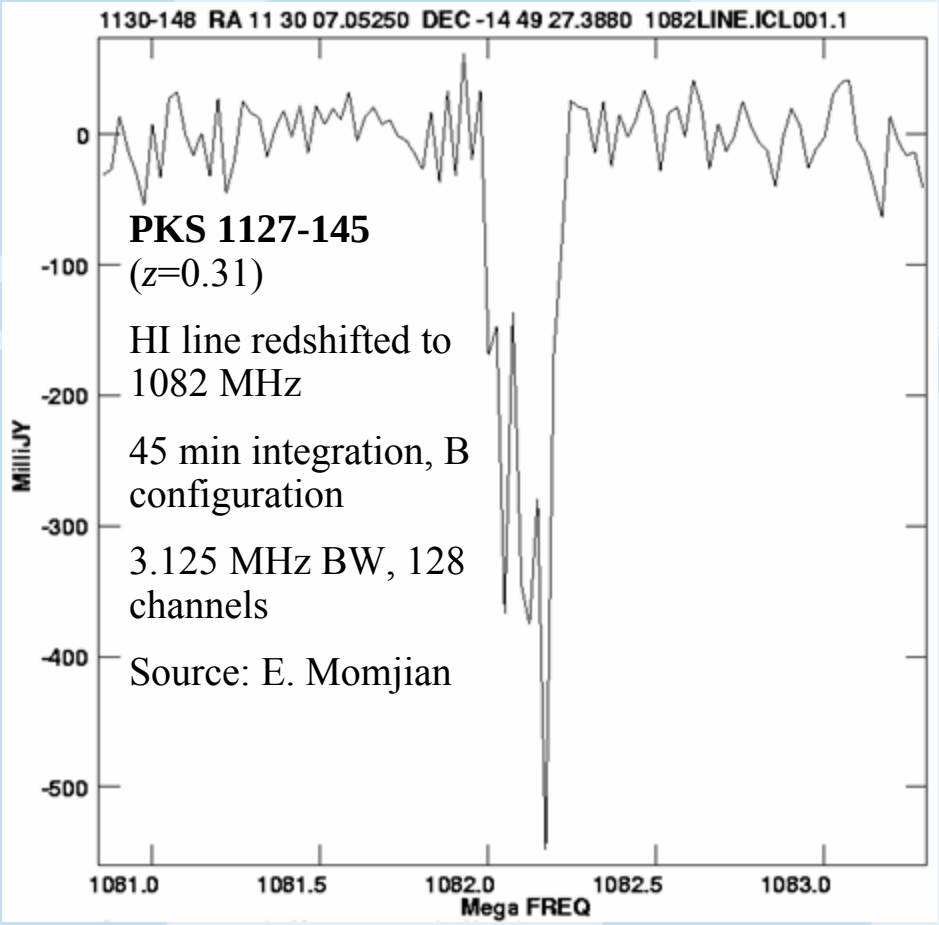
Sensitivity Improvement



(1σ, 12 hours: VLA Y2000 Black: EVLA Goals)

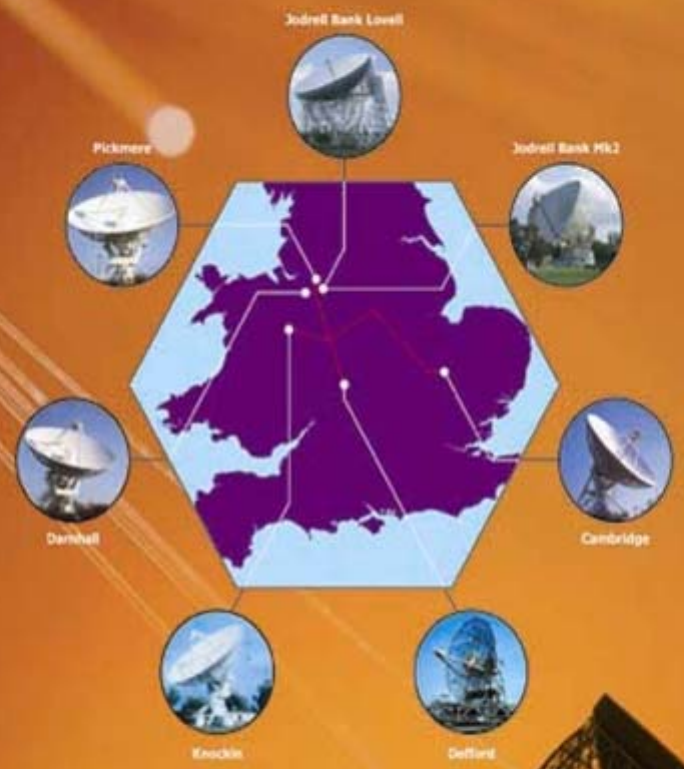
Redshifted Atomic (HI) and Molecular (OH) Gas in Absorption

- Access to new frequencies
- EVLA works to 1000 MHz now and eventually down to 940 MHz
- Surprise! RFI is benign
- Blind H/OH survey
  - trace gas evolution ahead of SKA
  - Complements DLA surveys
  - Full redshift range in one wide field



HI: 0< z <0.5
OH: 0< z <0.8

(Compare: Arecibo ALFALFA Survey to z<0.06)



e-MERLIN

Sensitivty: x30 improvement

Resolution: x7 over EVLA

Fibre in place: 210 Gbps

Receivers all in operation

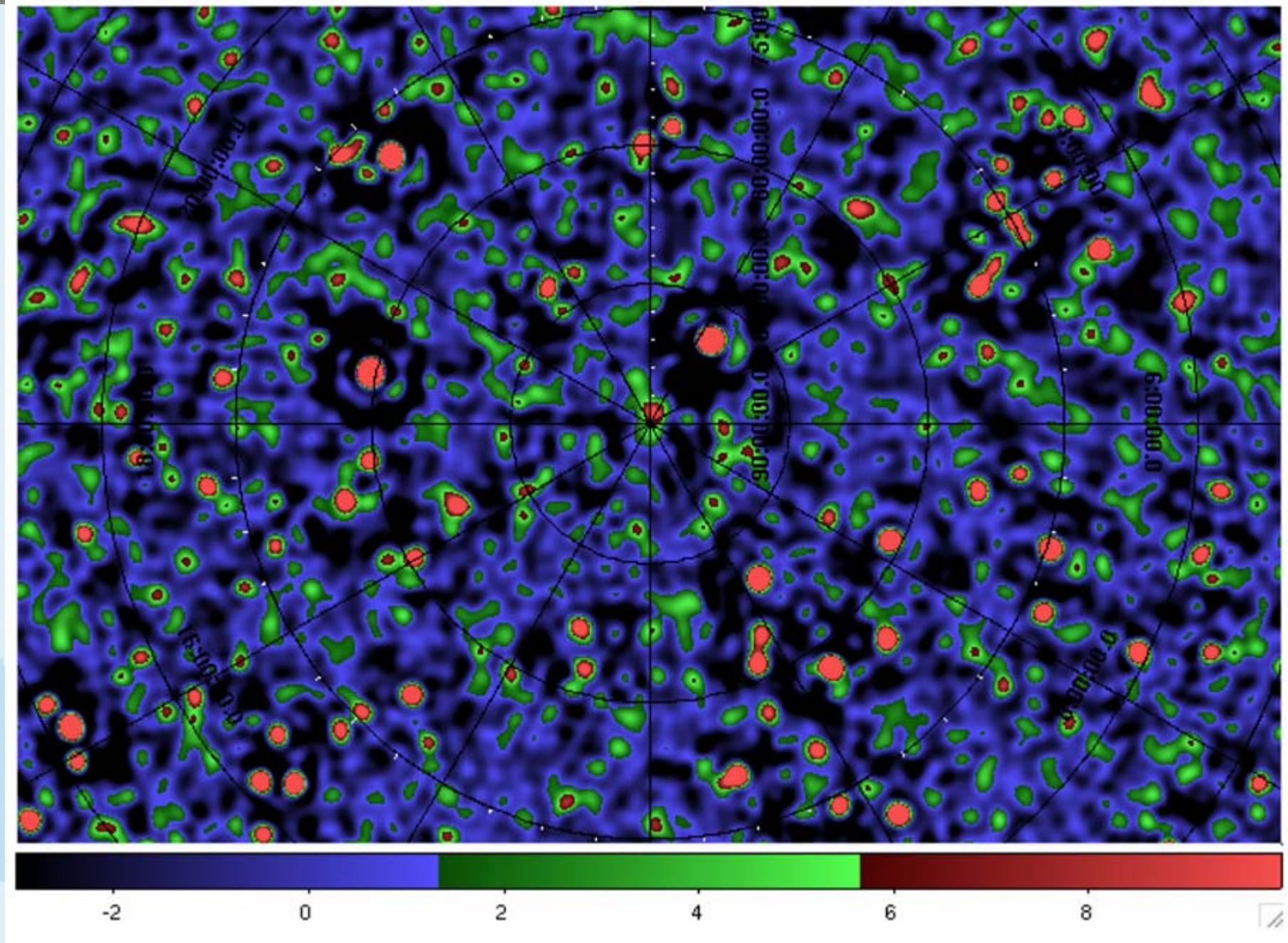
Correlator – same as EVLA

Early broadband science, Oct 2009

Band	Resolution	noise	Tb
L 1.3-1.8 GHz	150 mas	4 μJy	140 K
C 4-8 GHz	40 mas	1.4 μJy	50 K
K 22-24 GHz	10 mas	25 μJy	800 K

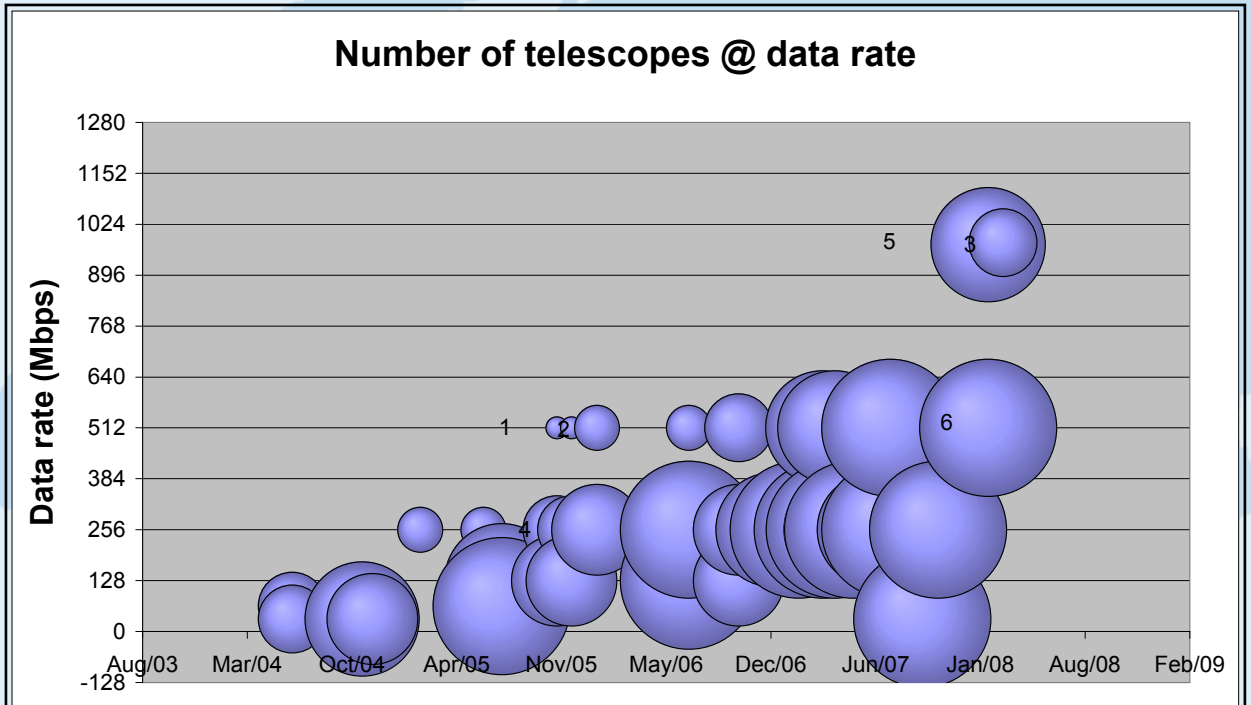
LOFAR

- Freq ranges: 20-80 MHz; 115-240 MHz
- 40-50 stations, 50% in core, remainder in 5-armed spiral
- Sensitivity after 4hr : @50MHz ~ 5mJy
  @150MHz ~ 0.3mJy
- Multi-beam instrument, simultaneous users
- Science goals: EoR, transients, deep extragalactic surveys, cosmic rays
- Operational: 2009


-2
0
2
4
6
8

e-VLBI

- Using fibres to connect telescopes around the world
- Real-time correlation of data: ‘the network is the telescope’
- Allowing real-time high-resolution science
- Moving to a future of routine VLBI, rapid response to transient events e.g. LOFAR/GLAST etc trigger.



e-VLBI

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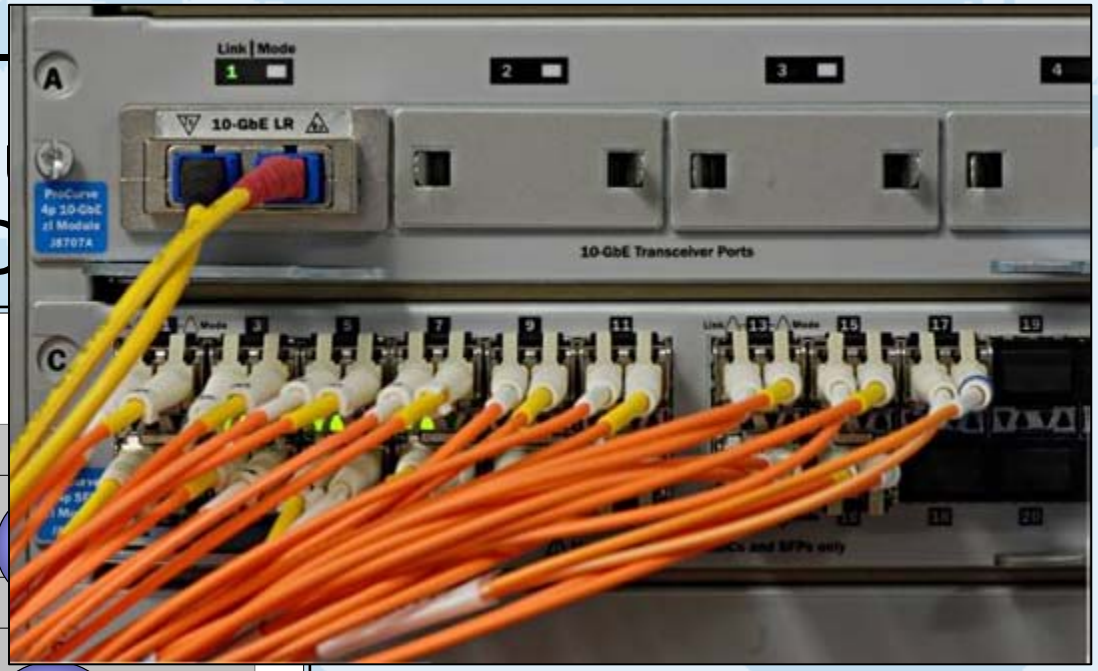
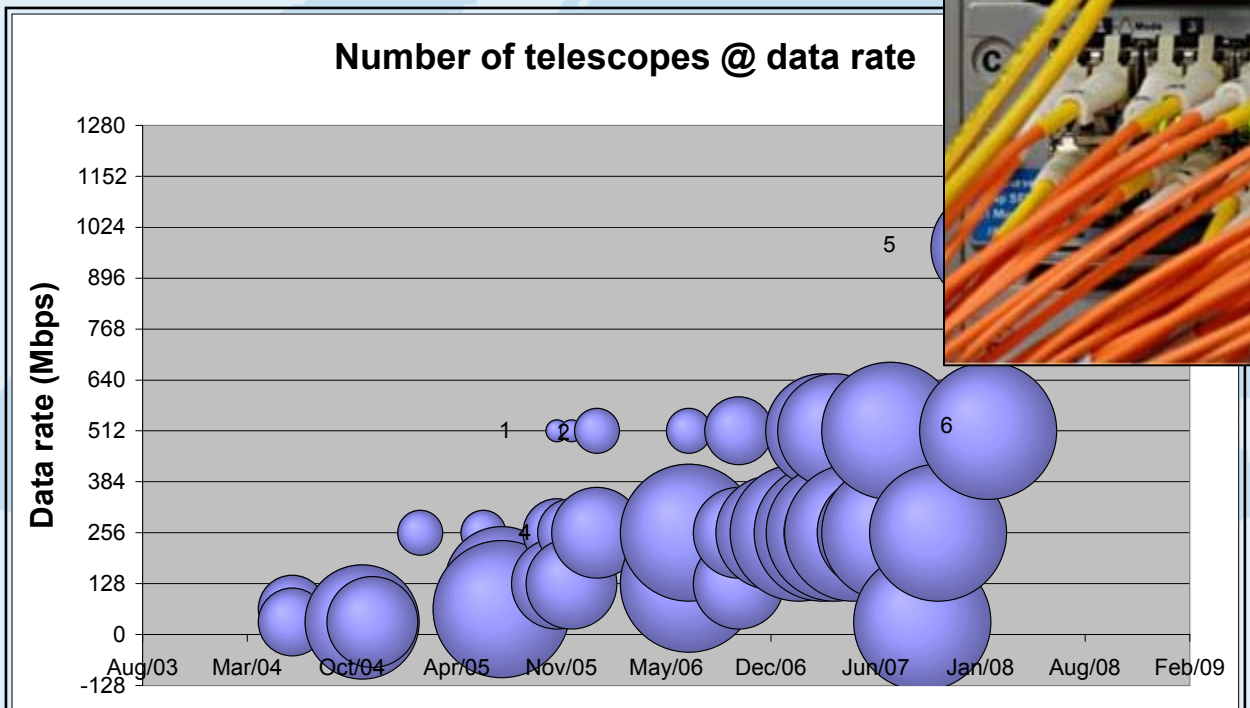
- Real-time correlation of data: ‘the network is the telescope’
- Allowing real-time high-
- Moving to a future of ro
transient events e.g. LC



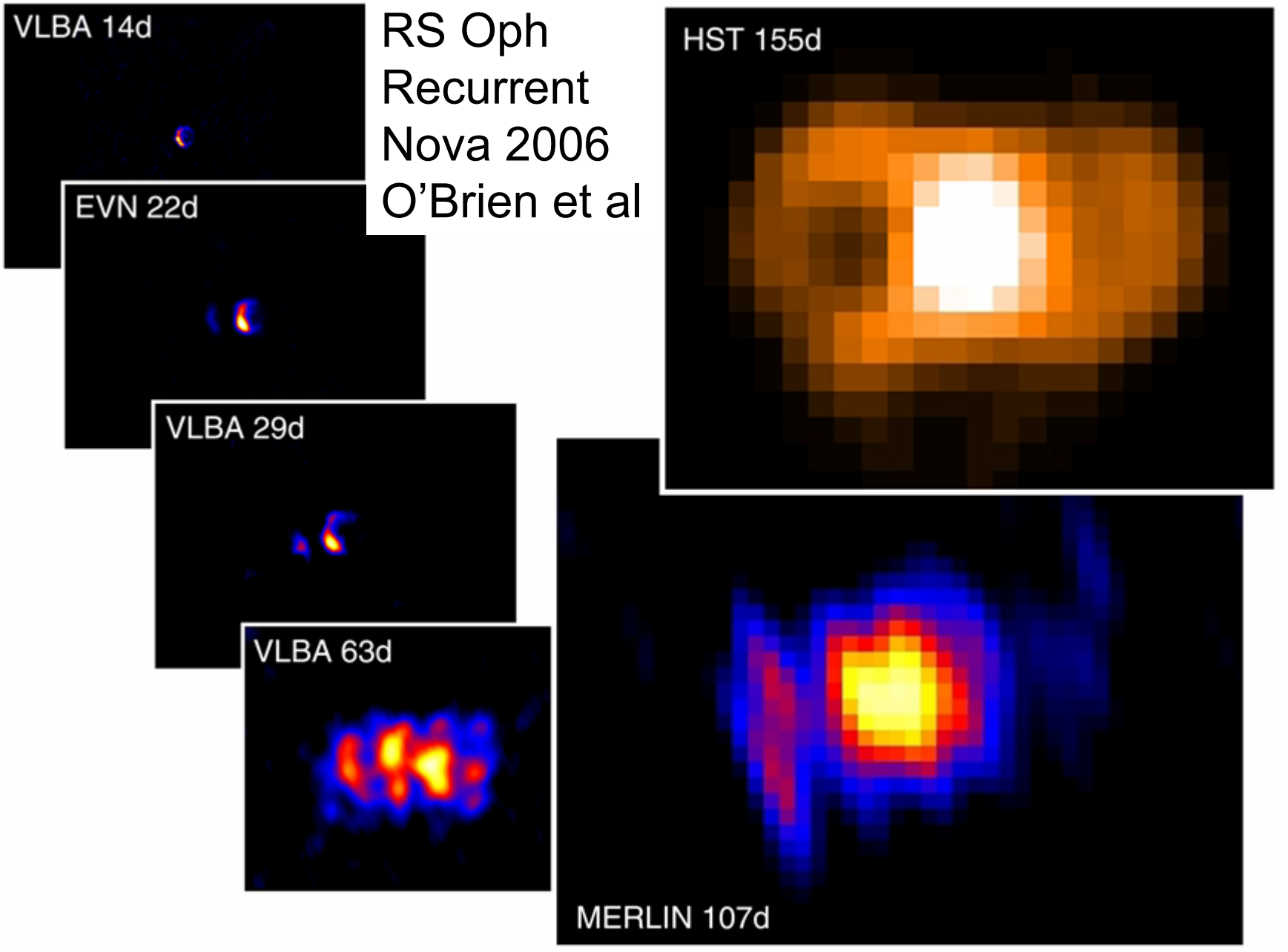


e-VLBI

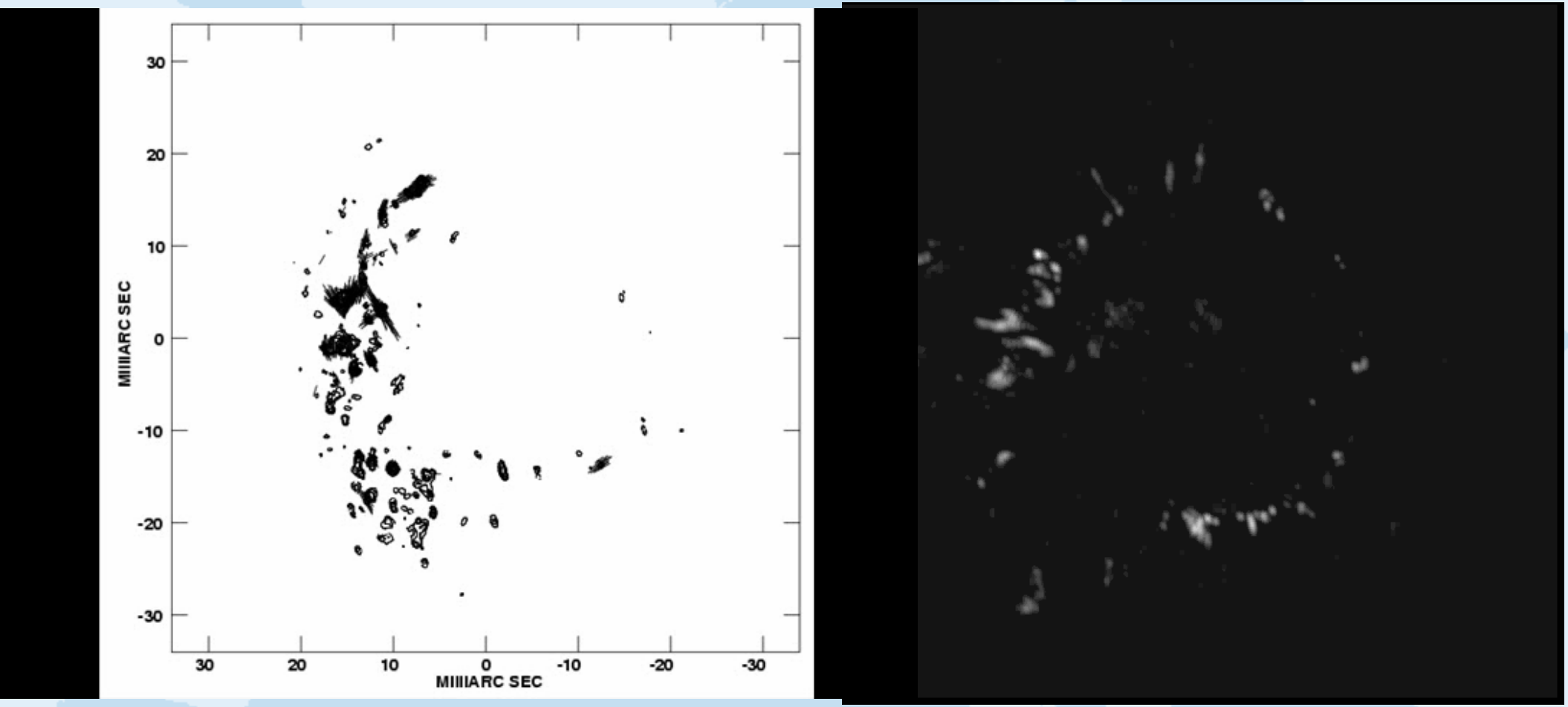
- Using fibres to connect telescopes around the world

e-VLBI

- RS Oph Recurrent Nova 2006 O'Brien et al



5D display problem



Kemball, Diamond & Gonidakis, in prep

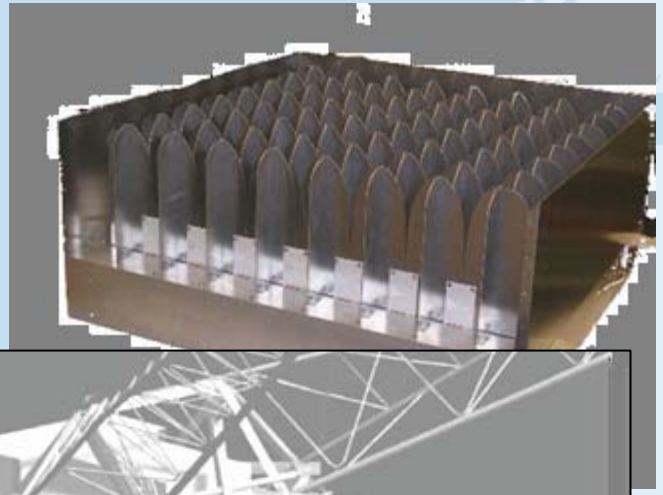
- VLBI spectro-polarimetric observations of SiO masers in Mira variable TX Cam with **500μarcsec** resolution
- Full movie is 121 epochs covering 2.5 years.

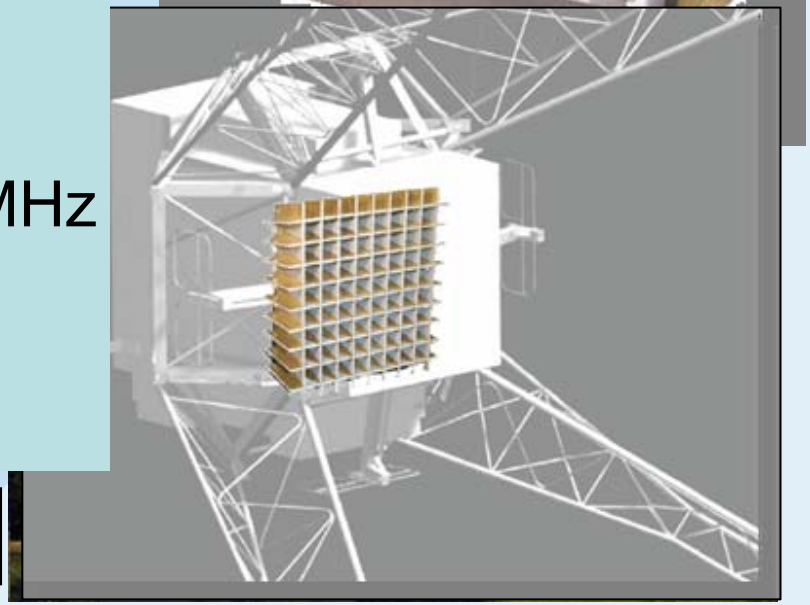
Wide fields of view: Apertif

- Sensitivity set by A_{eff}/T_{sys}
- Survey speed set by $(A_{eff}/T_{sys})^2$ x FoV
- Increase FoV on older telescope can provide new lease of life.

Apertif	WSRT
• 8x8 (x2) elements	1 (x2)
• 25 beams on the sky	1
• Range v: 900 – 1700 MHz	117 – 8650 MHz
• T_{sys} 50 K	30 K
• Bandwidth 300 MHz	160 MHz
• Aperture efficiency 75%	55%

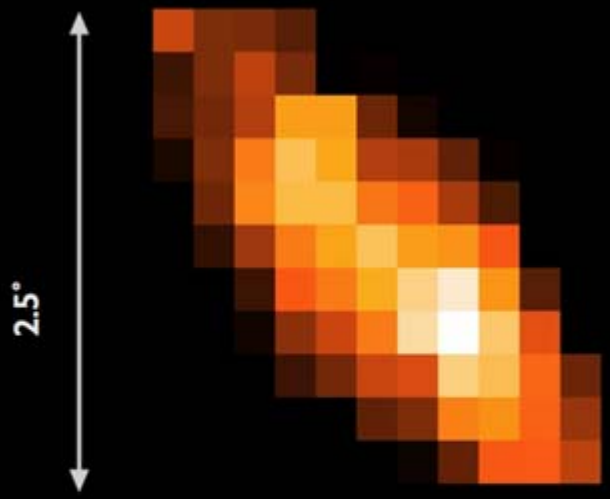
Survey speed compared to WSRT = 32






ASTRON
NWO

Data cube of M31



M31 with APERTIF prototype

1 dish, 1 pointing, 121 beams, 6.7s integration time

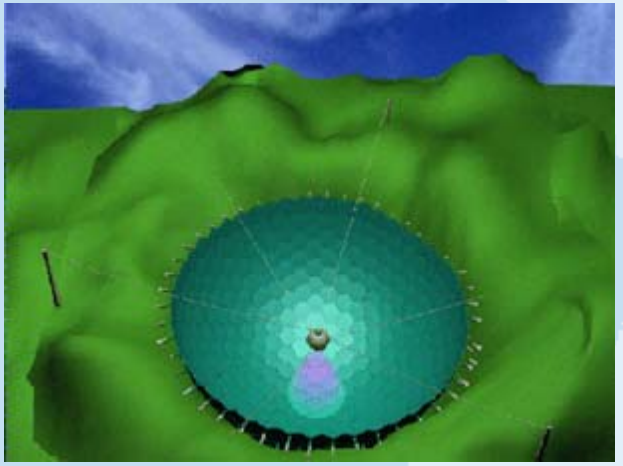
M31 with WSRT

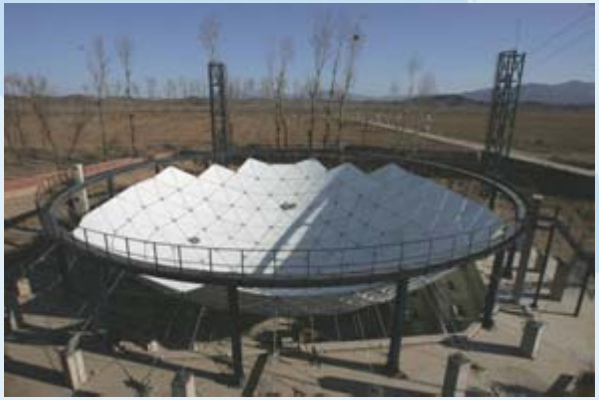
14 dishes, 163 pointings

R. Braun, 2002

FAST – a 500m aperture!

- NAOC in China has full funding for FAST – 500m Aperture Spherical Telescope.
- Arecibo-like BUT
  - Active surface
  - Stewart platform at focus with receiver package including multi-beam system at L-band (H line)
  - Can observe 60% Northern Sky
  - 10% SKA collecting area
  - Freq range: 30MHz → 3 GHz
- Major science goals: HI & pulsar surveys. Detect 10^7 galaxies out to z~0.15.
- Operational in 2013.





The Square Kilometre Array

Vital Statistics

1 km^2 collecting area

Continental Scale

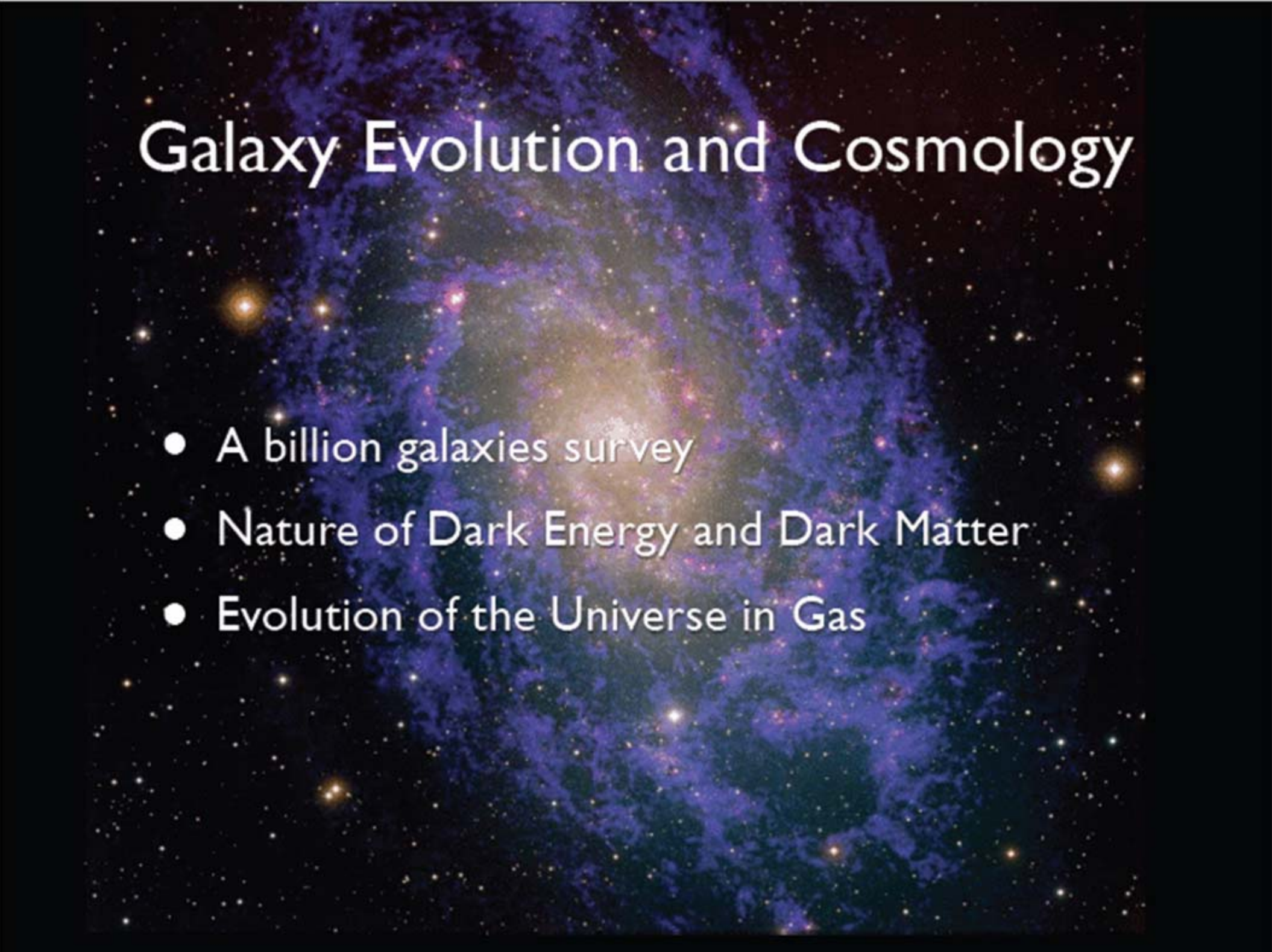
- Core: 5 x 5 km
- Remote: >3000km

Sensor Network

- 10^{18} Flop
- 10^{12} bits/sec

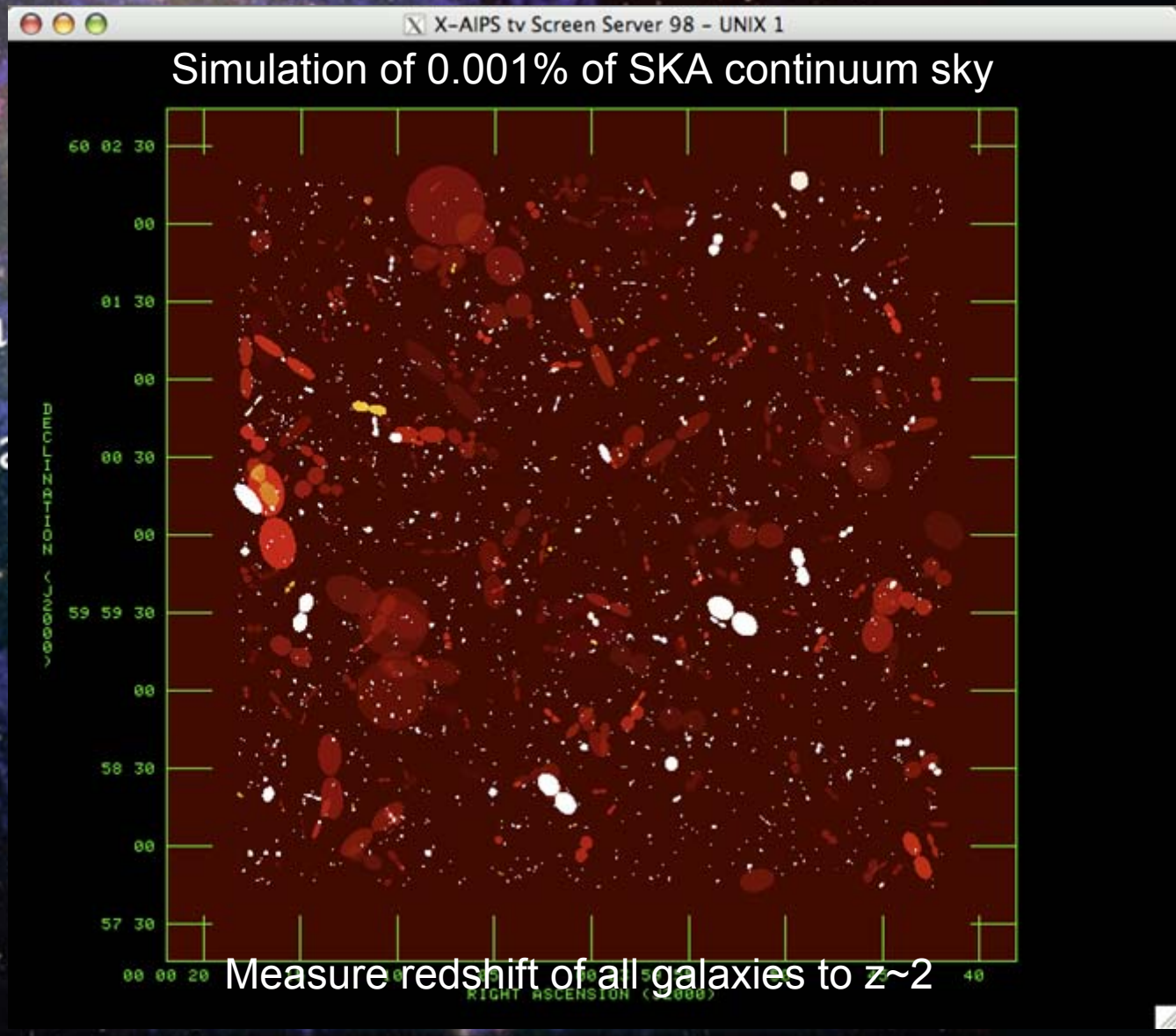
Dark Ages

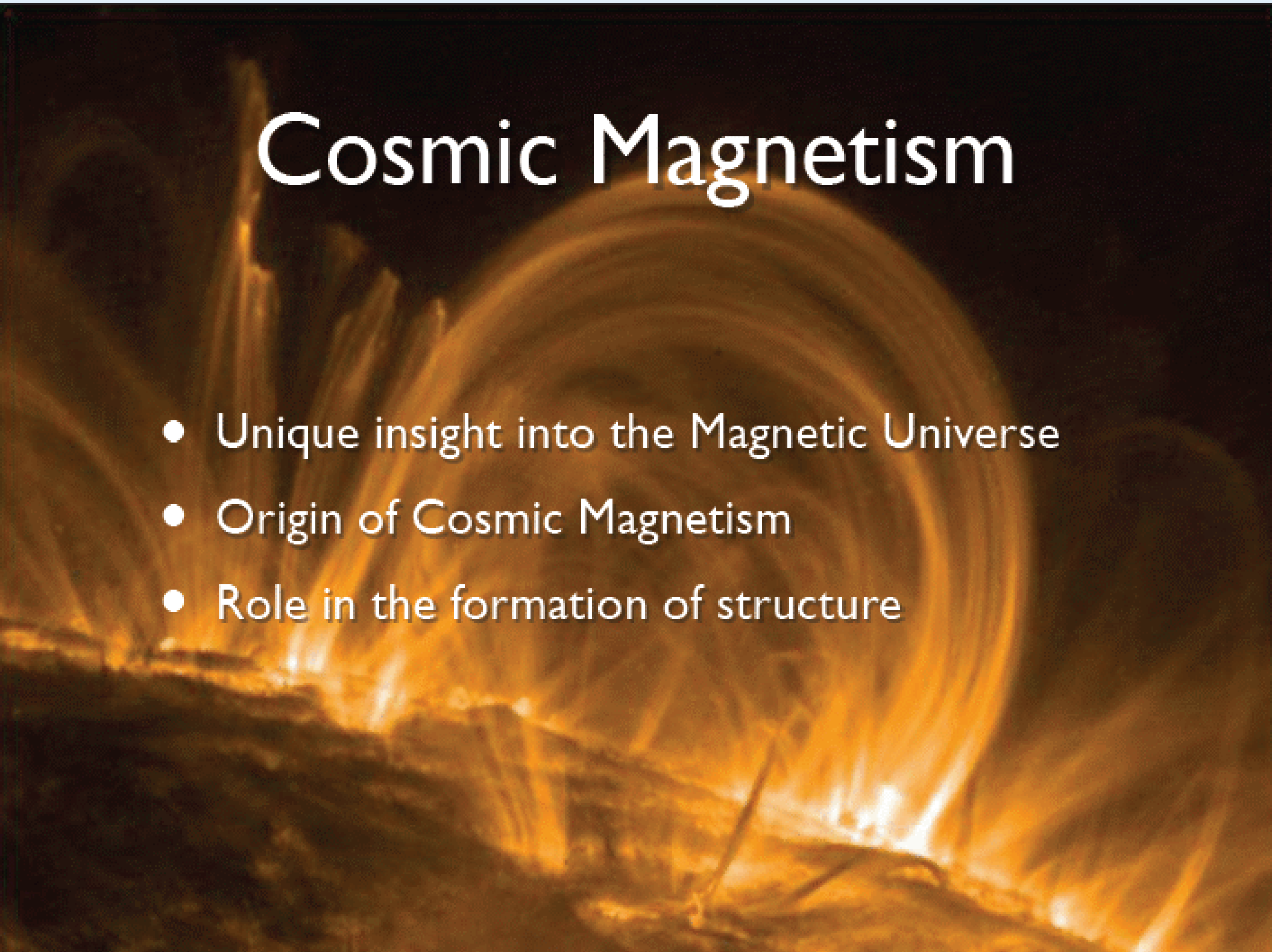
- Emergence of the First Stars in the Universe
- Influence on evolution of the Universe


Galaxy Evolution and Cosmology
A billion galaxies survey
Nature of Dark Energy and Dark Matter
Evolution of the Universe in Gas

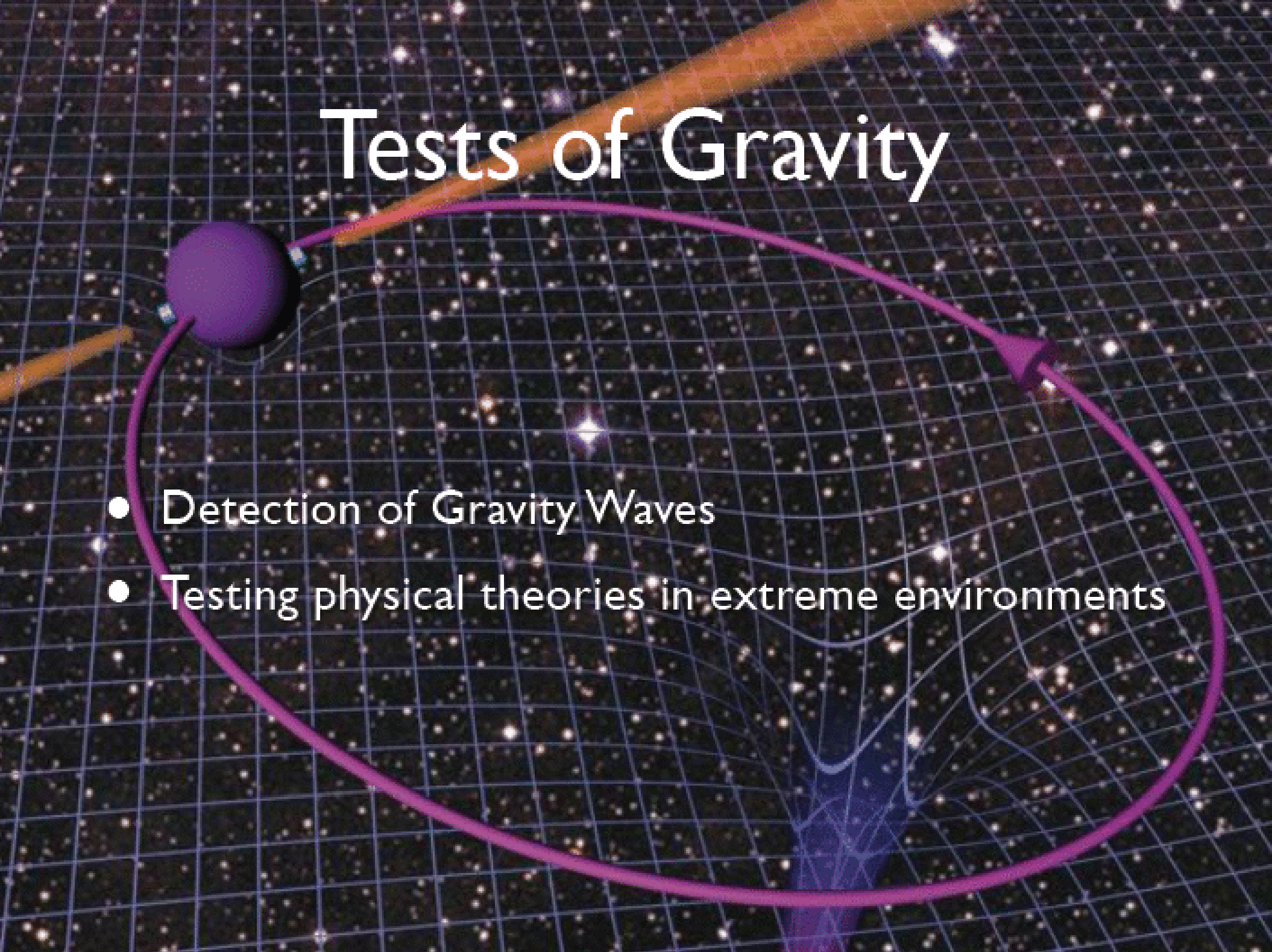
Galaxy Evolution and Cosmology

- A billion gala
- Nature of D
- Evolution of



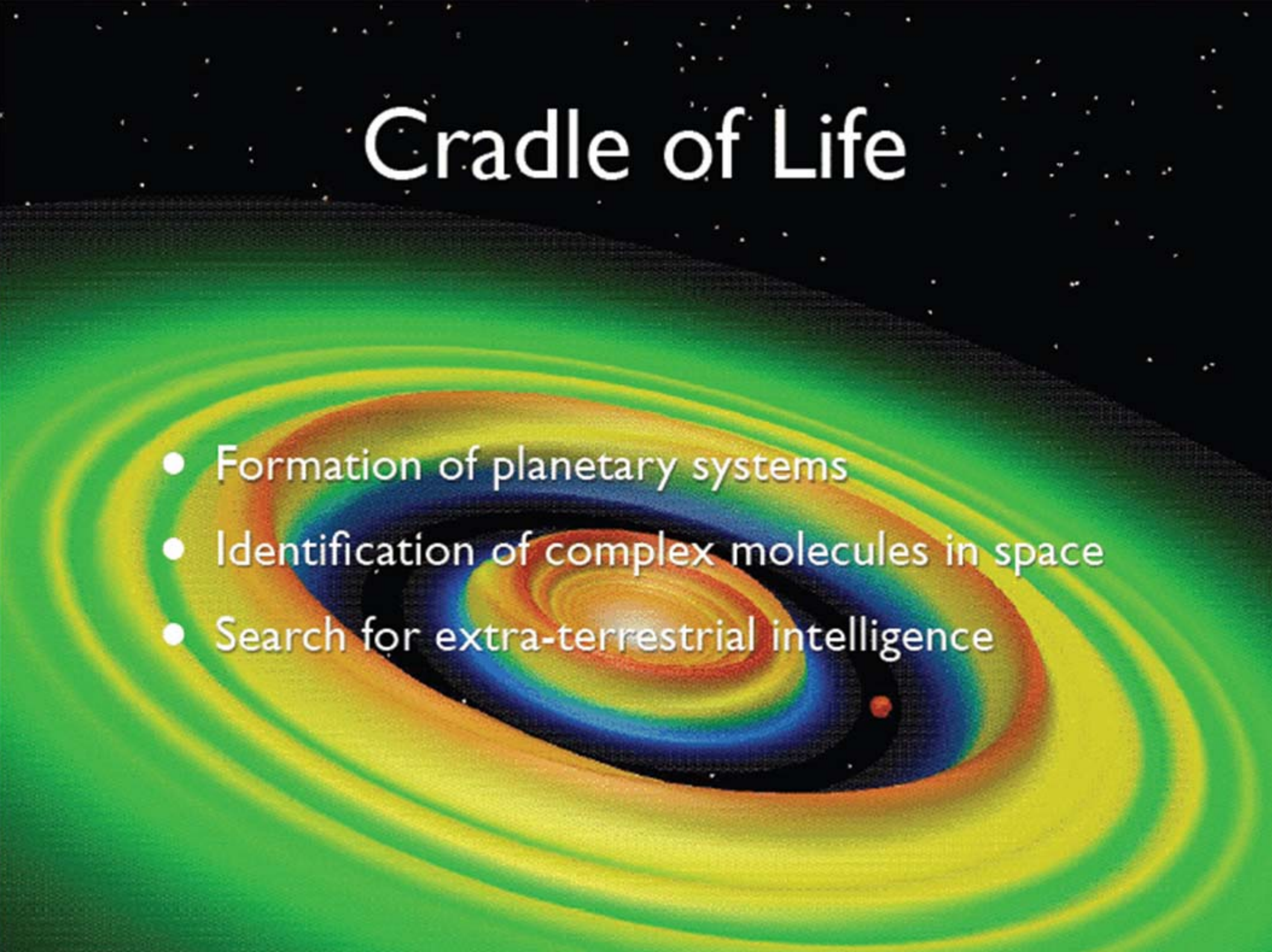

Cosmic Magnetism
• Unique insight into the Magnetic Universe
• Origin of Cosmic Magnetism
• Role in the formation of structure

Tests of Gravity



- Detection of Gravity Waves
- Testing physical theories in extreme environments

Cradle of Life

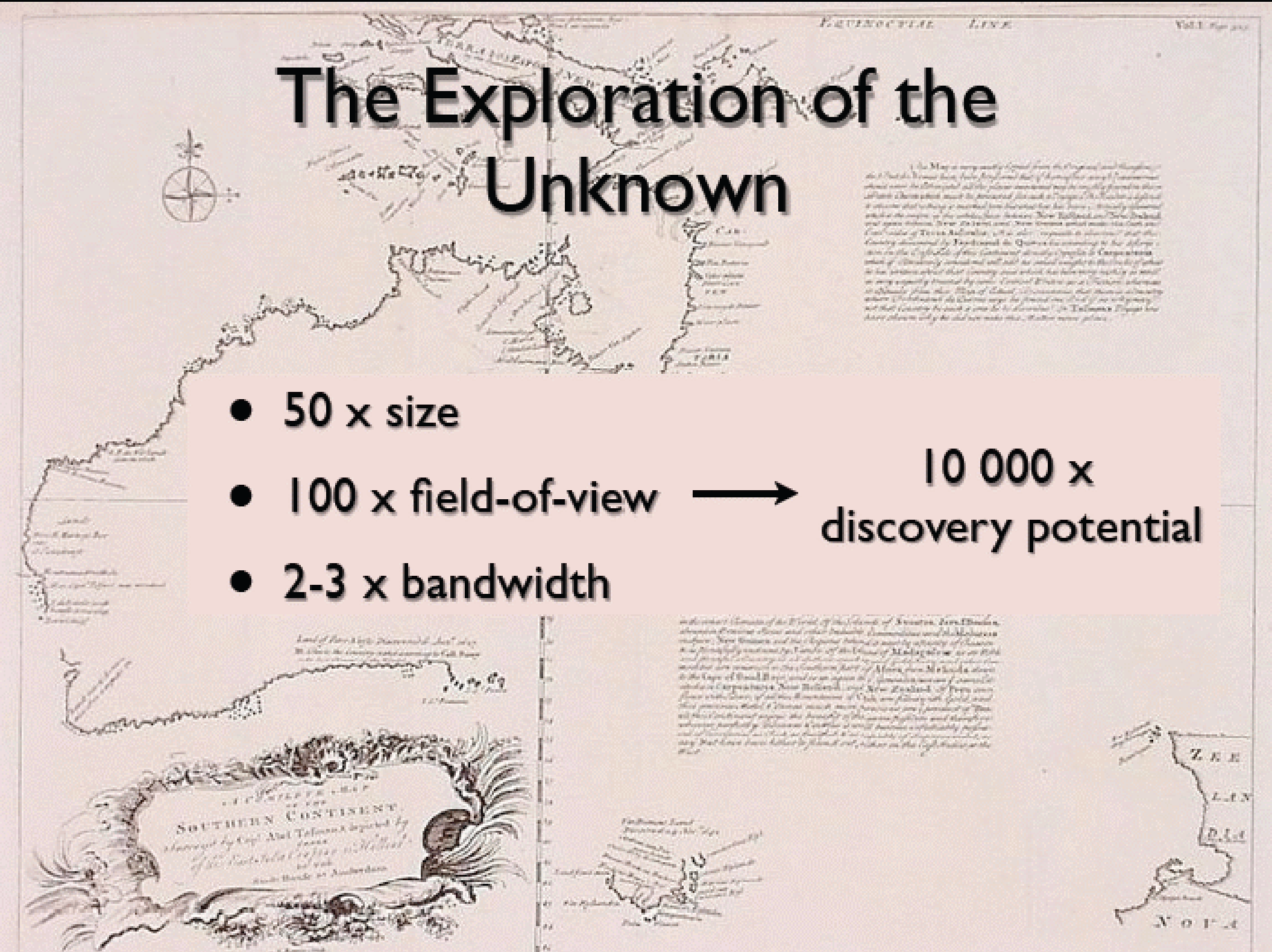


- Formation of planetary systems
- Identification of complex molecules in space
- Search for extra-terrestrial intelligence

The Exploration of the Unknown

- 50 x size
- 100 x field-of-view
- 2-3 x bandwidth

→ 10 000 x discovery potential



SKA Specifications

- SKA will cover the frequency range 70 MHz to > 25 GHz
- Requires two fundamental receptor technologies sharing the same infrastructure:
  - ~3000 15m dishes with smart feeds: > ~1GHz
  - Aperture arrays: < ~1 GHz
  - See SKA Memo 100: www.skatelescope.org
- SKA, and astronomy community, will benefit from a phased construction plan:
  - Phase 1: 10-15% collecting area, covering 0.5 – 10 GHz, compact configuration with ~500 dishes + aperture array
  - Phase 2: full collecting area, 70MHz – 10 GHz, spread over 3000km
  - Phase 3: extend frequency coverage
- Target cost:
  - Phase 1: €300M
  - Phase 2: €1200M
  - Phase 3: not yet investigated

SKA Status

19 Countries in Europe, North America, Africa, Australasia, Asia,
55 institutes
15 Funding Agencies in the International SKA Forum
€140M R&D programme from 2008-2012

SKA Status

America, Africa, Australasia, Asia,

ernational SKA Forum
2008-2012

SKA Status

USA

America, Africa, Australasia, Asia,

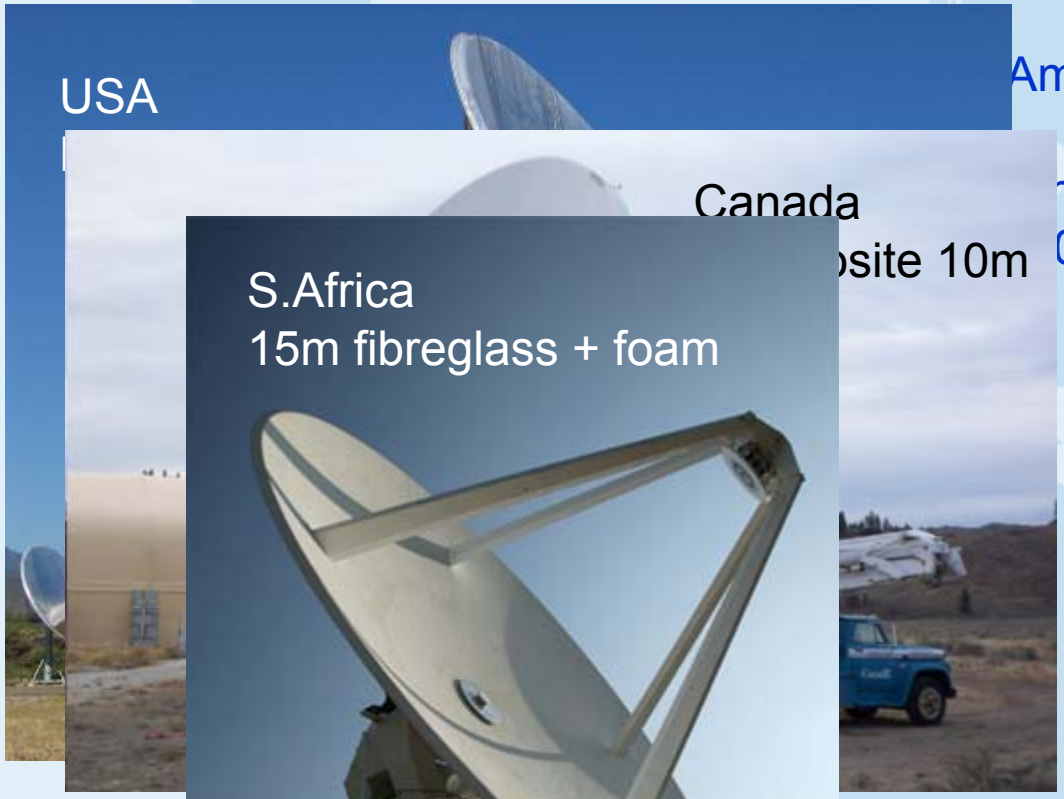
national SKA Forum
08-2012

Canada
Composite 10m

SKA Status

America, Africa, Australasia, Asia,

national SKA Forum
08-2012



SKA Status

America, Africa, Australasia, Asia,

national SKA Forum
08-2012

USA

Canada
osite 10m

S.Africa
15m fibreglass + foam

Australia
12m stretch
panel

SKA Status

America, Africa, A

national SKA Fo

08-2012

USA

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SKA Status

USA

America, Africa, A

Canada

national SKA

osite 10m

08-2012

S.Africa
15m fibreglass + foam

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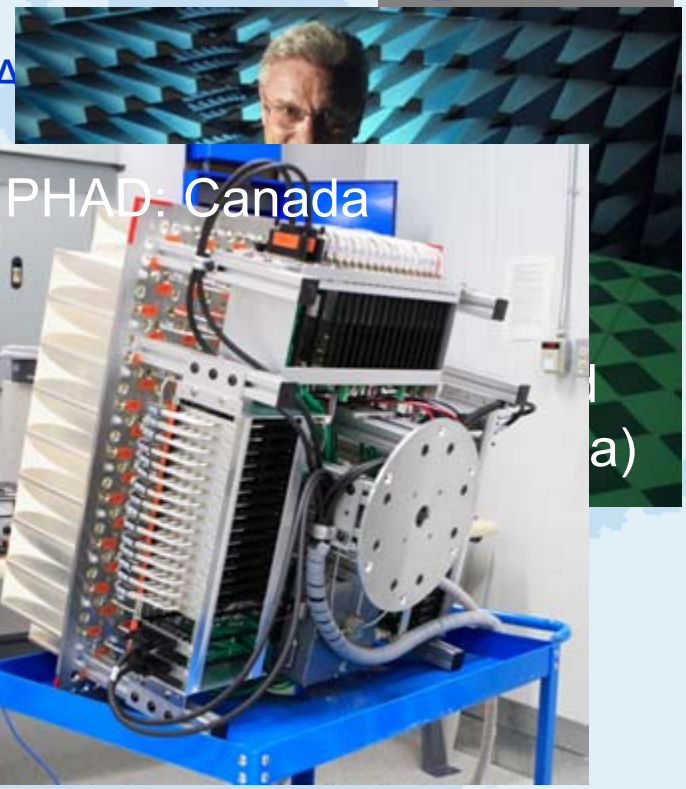

PHAD: Canada

SKA Status

USA

America, Africa, A

Canada

national SKA

osite 10m

08-2012

S.Africa
15m fibreglass + foam

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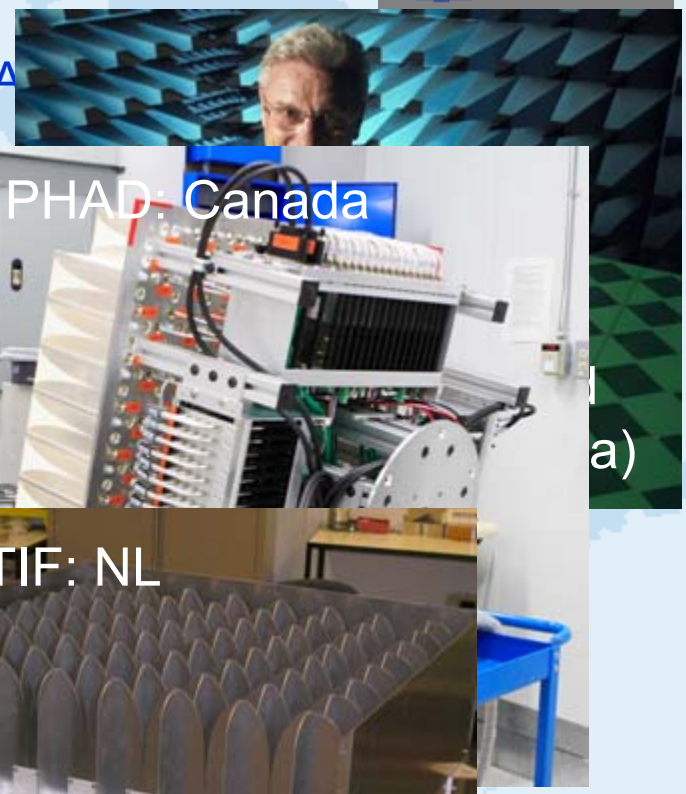

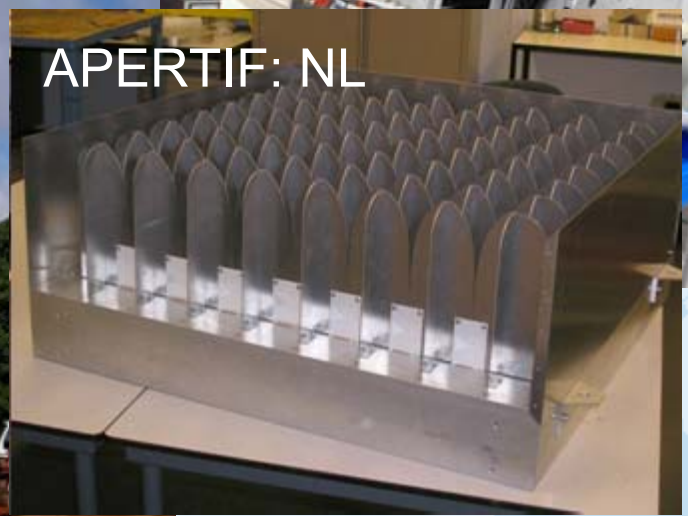

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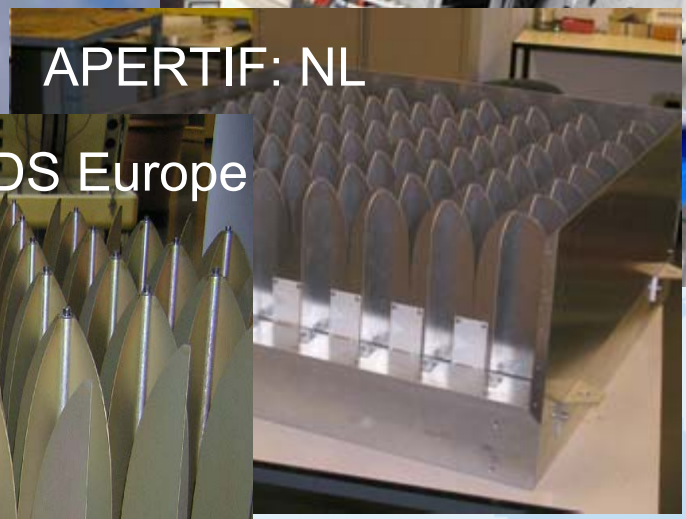


APERTIF: NL

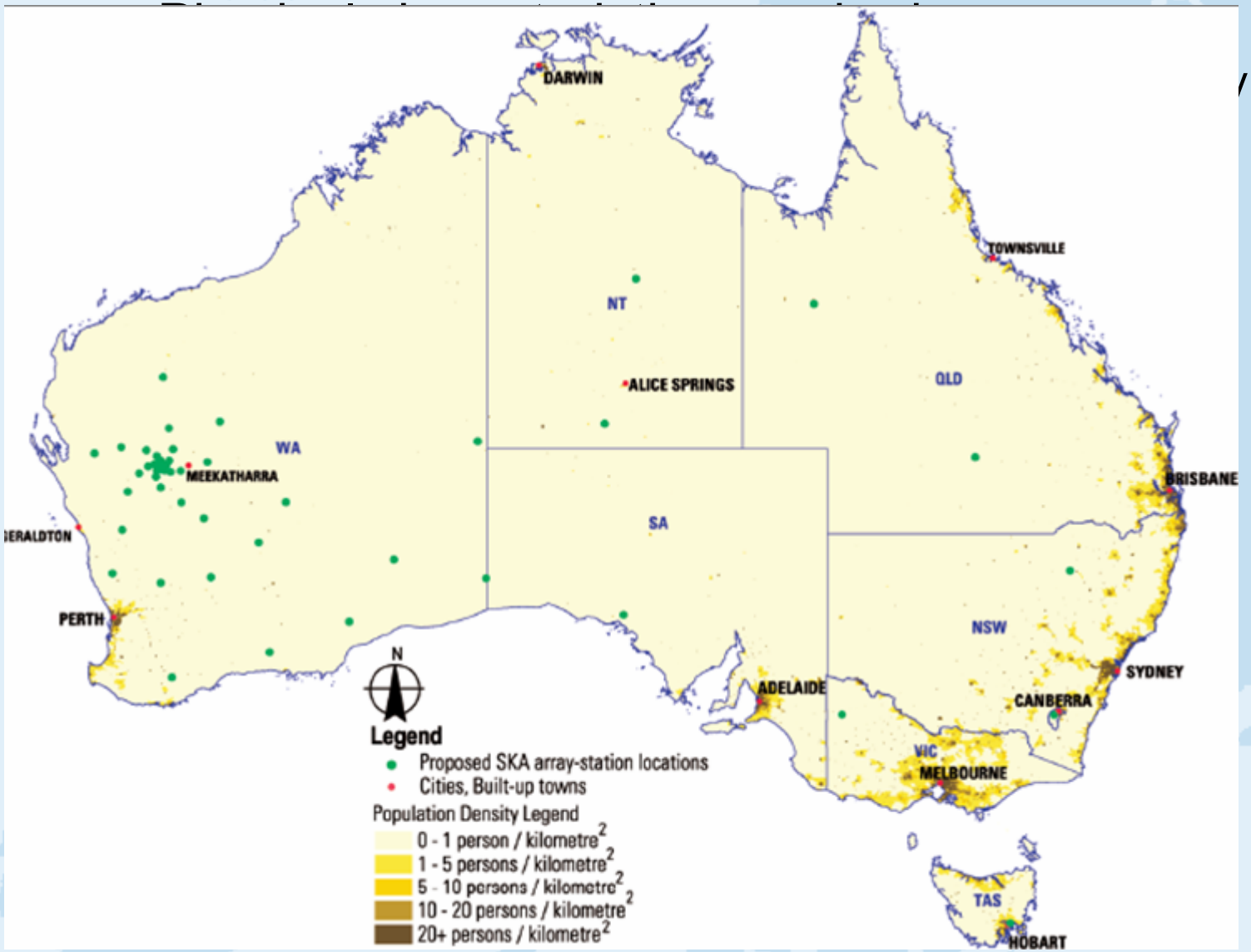
Aperture arrays: SKADS Europe

SKA Site selection

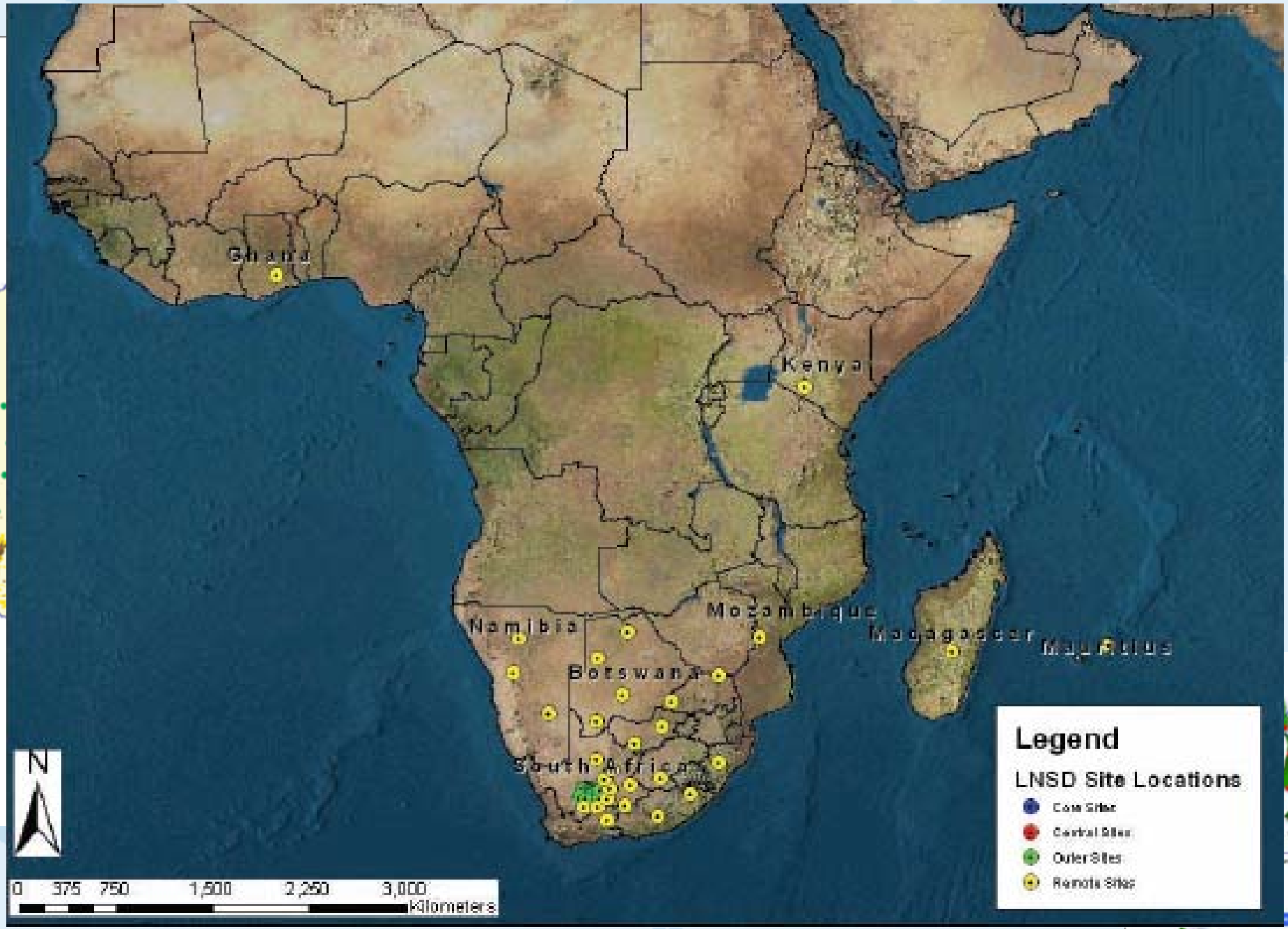
- Physical characteristics required
  - Very quiet radio frequency environment, particularly for the core region
  - Large physical extent (>3000 km)
  - Low ionospheric turbulence
  - Low troposphere turbulence

SKA Site selection

for the core region



SKA Site selection



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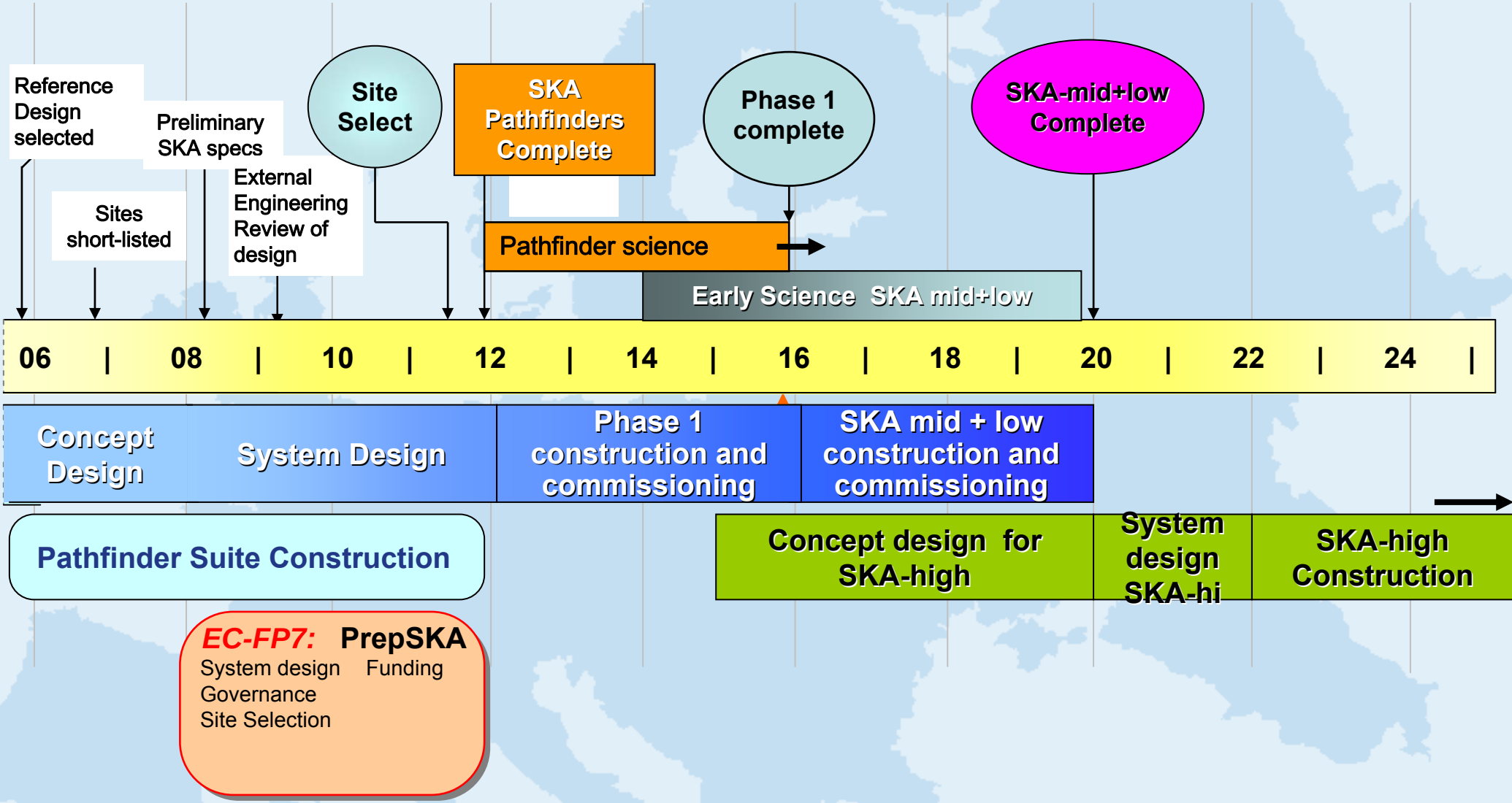
Reference Design selected
Preliminary SKA specs
Sites short-listed
External Engineering Review of design
Site Select
SKA Pathfinders Complete
Phase 1 complete
SKA-mid+low Complete
Pathfinder science
Early Science SKA mid+low
06
08
10
12
14
16
18
20
22
24
Concept Design
System Design
Phase 1 construction and commissioning
SKA mid + low construction and commissioning
Pathfinder Suite Construction
Concept design for SKA-high
System design SKA-hi
SKA-high Construction
EC-FP7: PrepSKA
System design
Funding
Governance
Site Selection