

Building the World's Biggest Telescope:

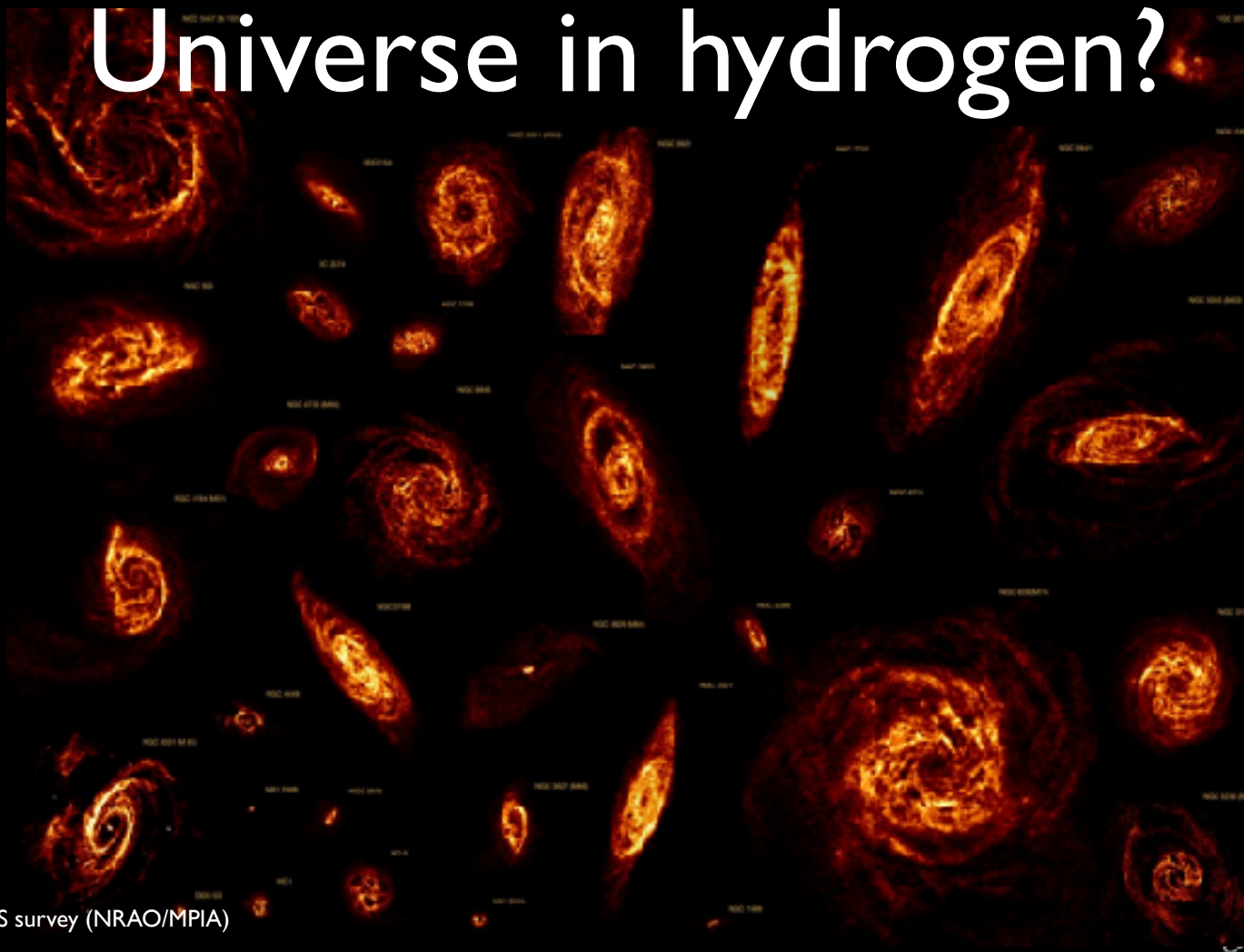


The **S**quare **K**ilometre **A**rray

Naomi McClure-Griffiths

The Australian National University

The 1991 concept: What does it take to read the history of the Universe in hydrogen?



Credit: THINGS survey (NRAO/MPIA)

A: A radio telescope 1 km^2
in area



SKA Science

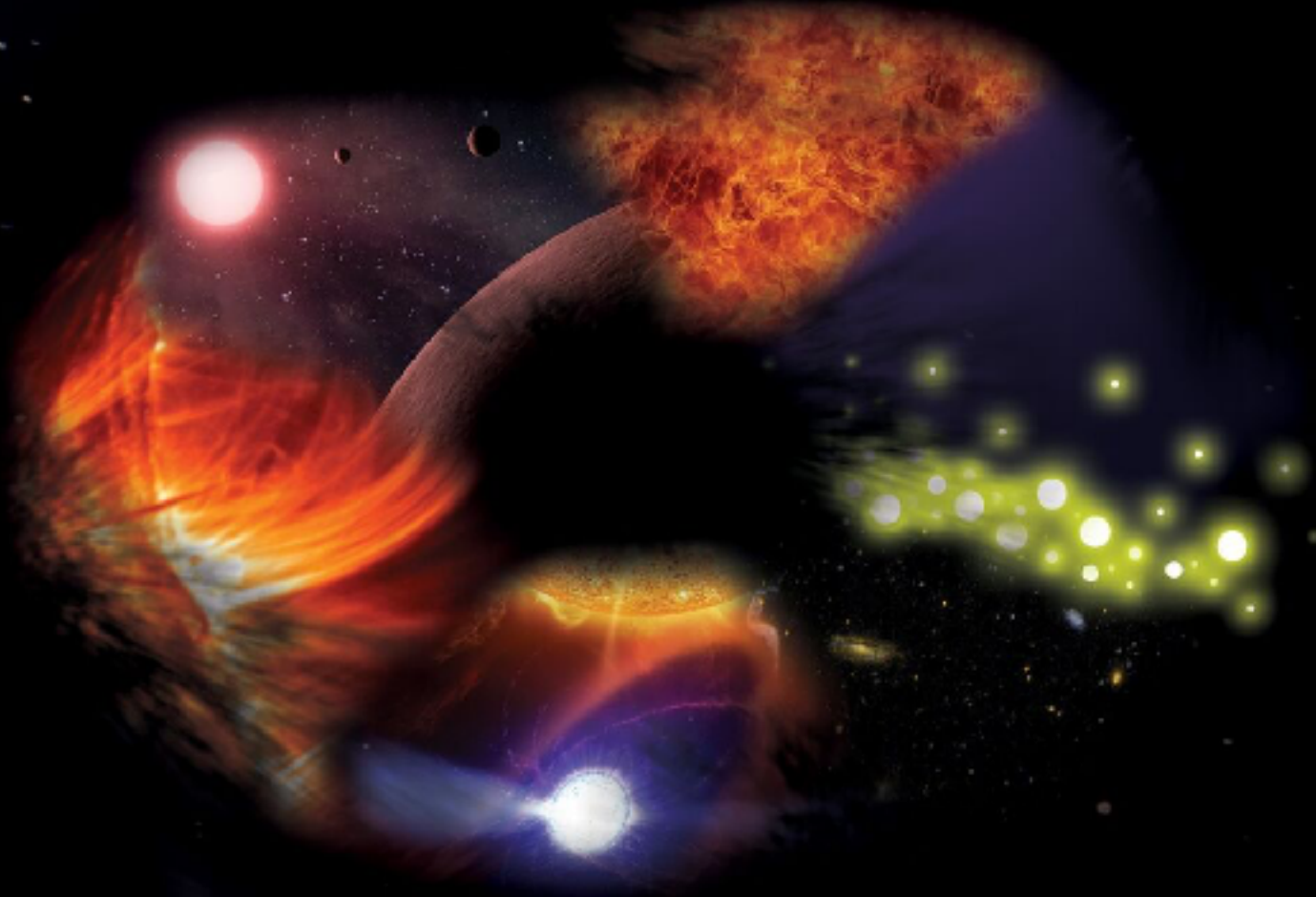


Image credit: SKA Telescope

SKA Science

The dawning of the cosmos -

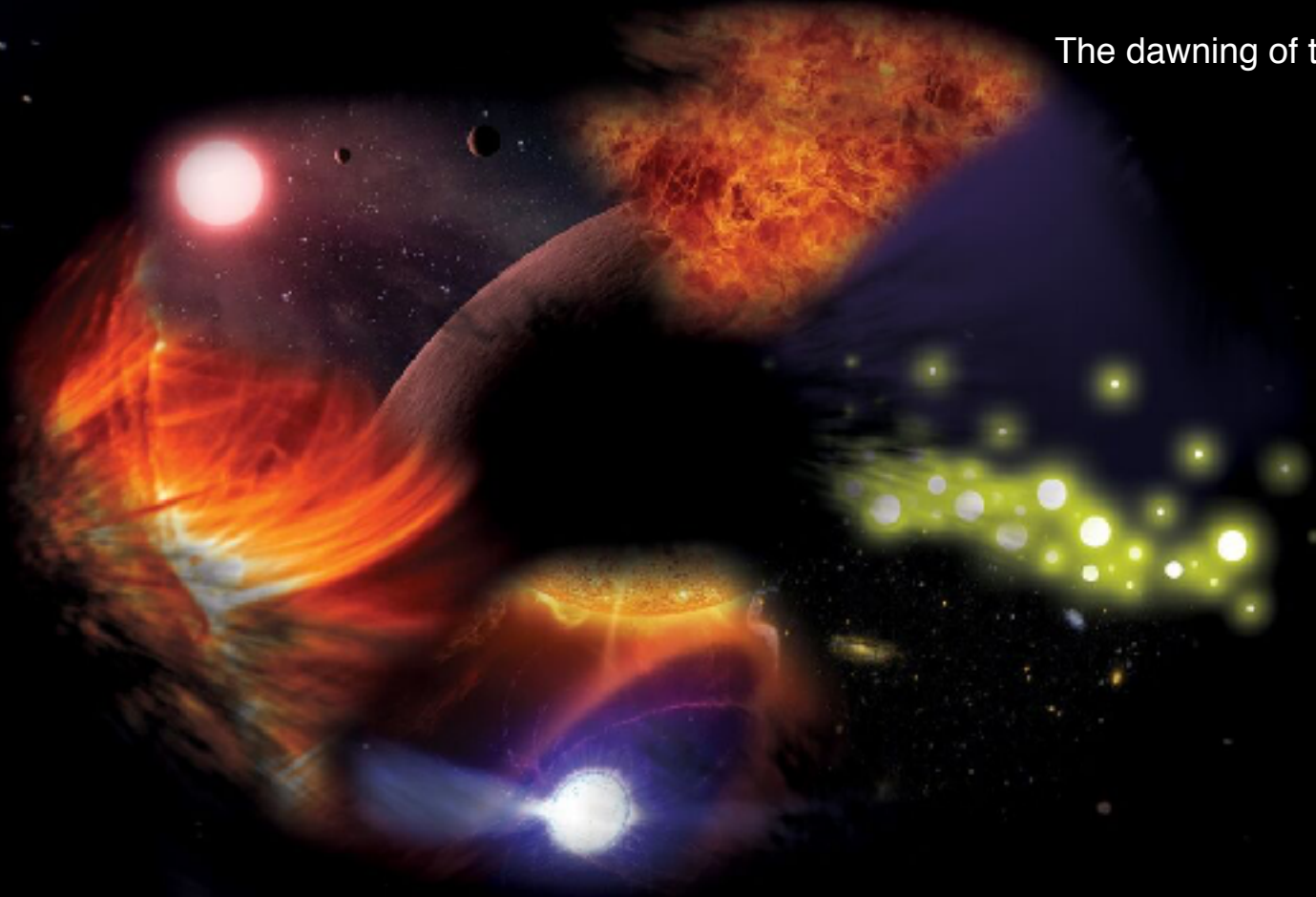


Image credit: SKA Telescope

SKA Science

The dawning of the cosmos -
formation of the first stars

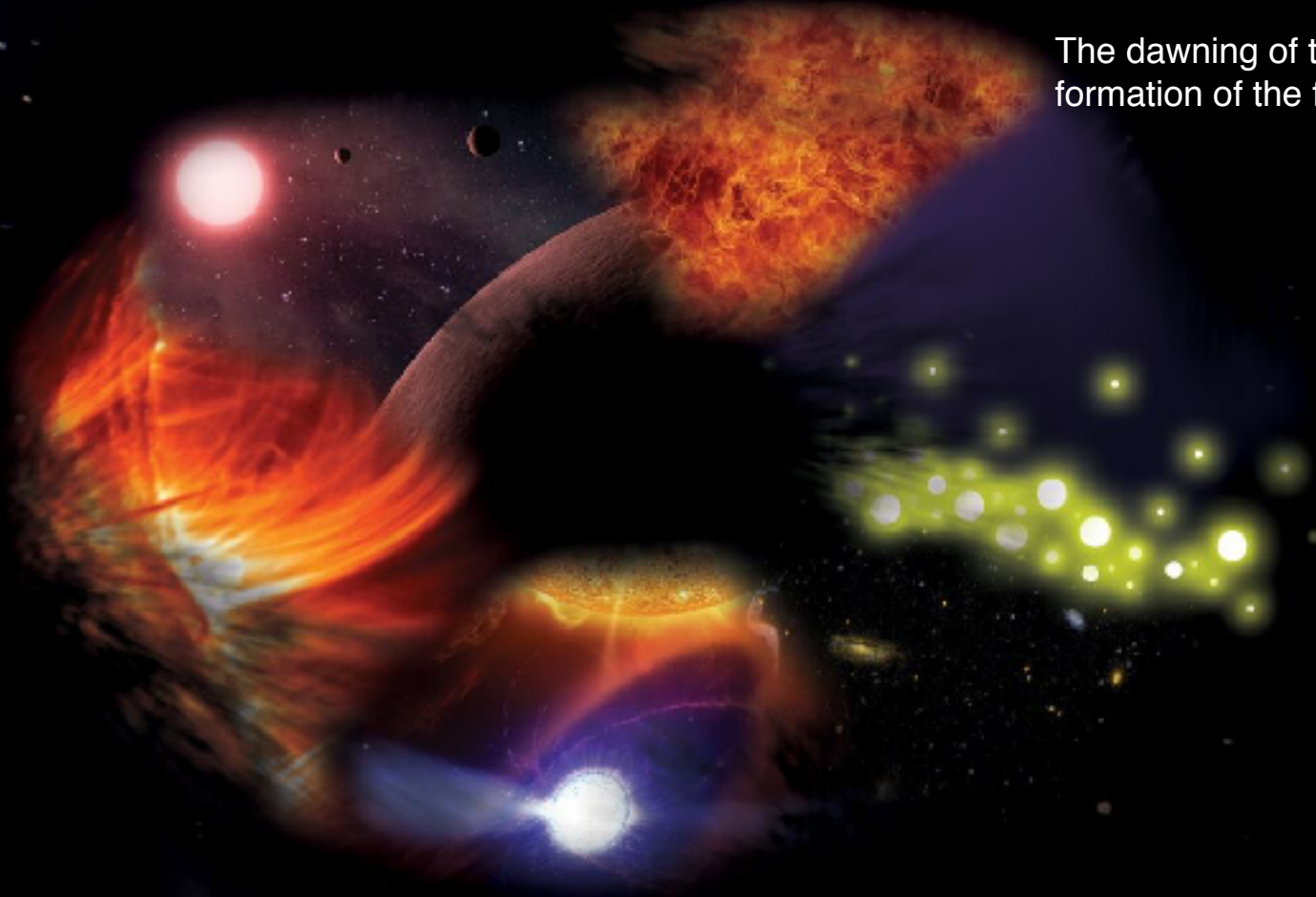


Image credit: SKA Telescope

SKA Science

The dawning of the cosmos -
formation of the first stars

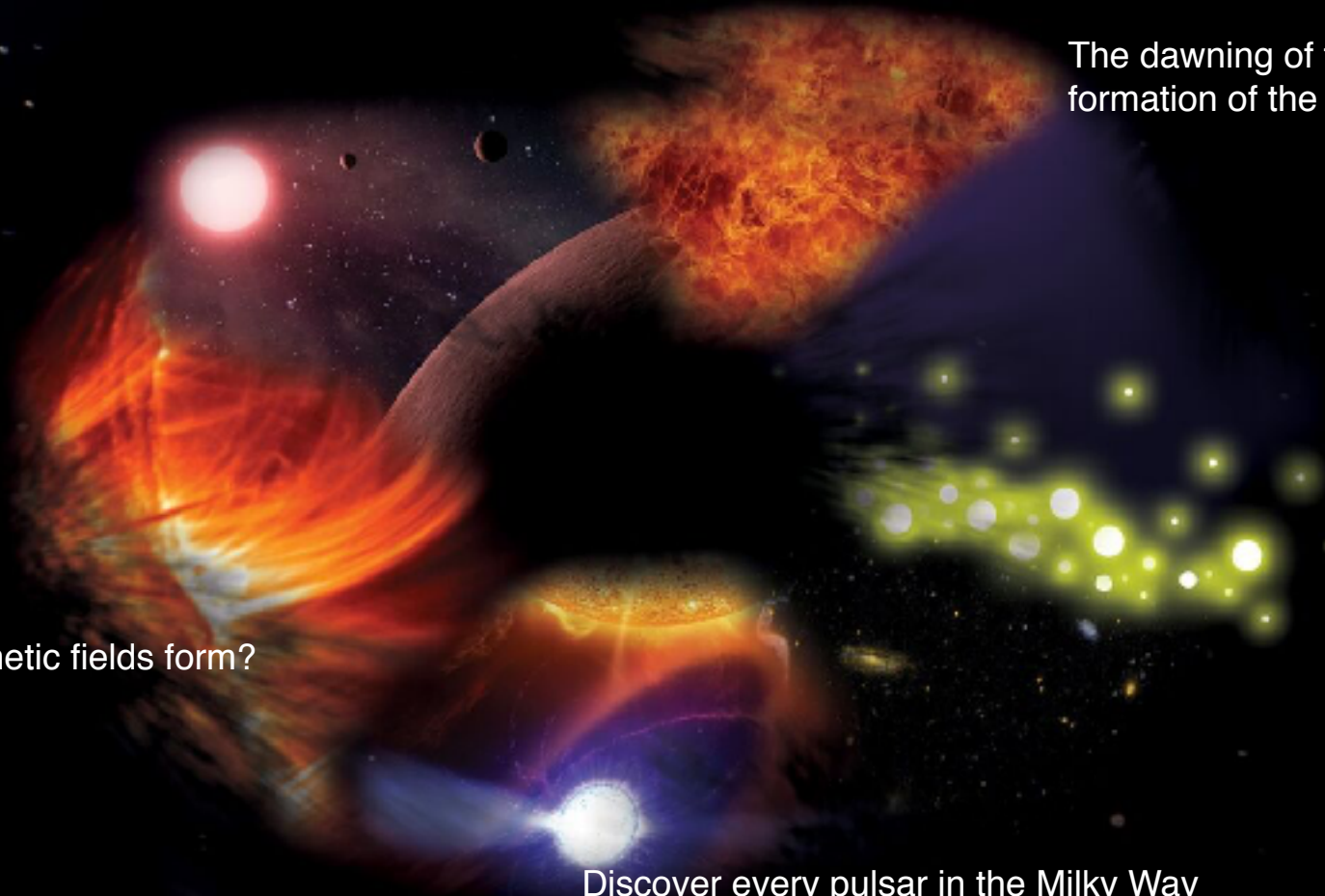
Discover every pulsar in the Milky Way

SKA Science

The dawning of the cosmos -
formation of the first stars

How did magnetic fields form?

Discover every pulsar in the Milky Way



SKA Science

The background image is a composite of four distinct astronomical scenes. In the upper left, a bright red star is surrounded by a glowing orange and red nebula. In the upper right, a cluster of yellow-green stars is visible against a dark background. In the lower left, a blue and purple pulsar is shown with a bright white spot at its core. In the lower right, a cluster of yellow-green stars is visible against a dark background.

The dawning of the cosmos -
formation of the first stars

How did magnetic fields form?

How the Universe has evolved

Discover every pulsar in the Milky Way

SKA Science

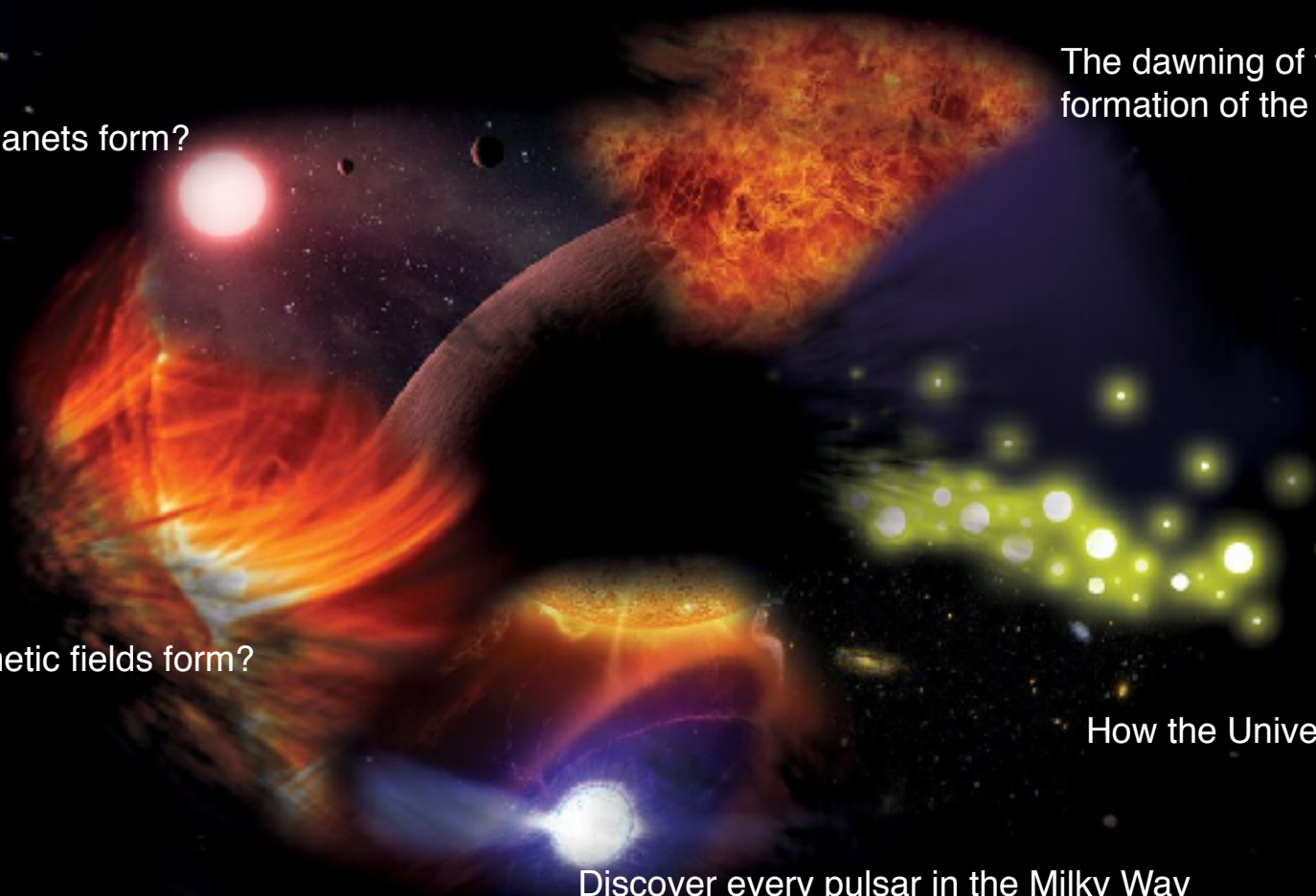
How do planets form?

The dawning of the cosmos -
formation of the first stars

How did magnetic fields form?

How the Universe has evolved

Discover every pulsar in the Milky Way



SKA Science

How do planets form?

The dawning of the cosmos -
formation of the first stars

Are we alone?

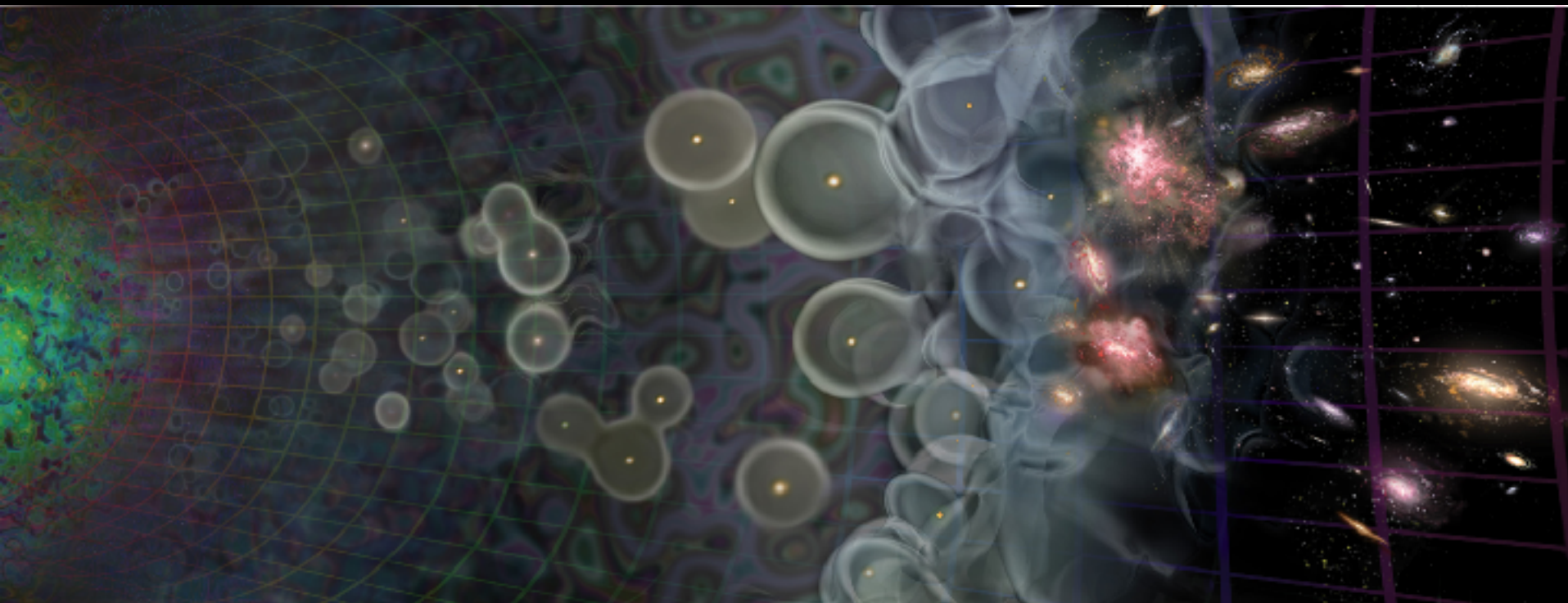
How did magnetic fields form?

How the Universe has evolved

Discover every pulsar in the Milky Way

The Cosmic Dawn

Credit: Loeb/CfA/UC Boulder



Big Bang

~500 Myr

~1 Gyr

~13 Gyr

SKA2: Direct imaging of
Cosmic Dawn ($z = 12 - 30$).

SKA1: Direct imaging of
EoR structures ($z = 6 - 12$). Power spectrum of
Cosmic Dawn

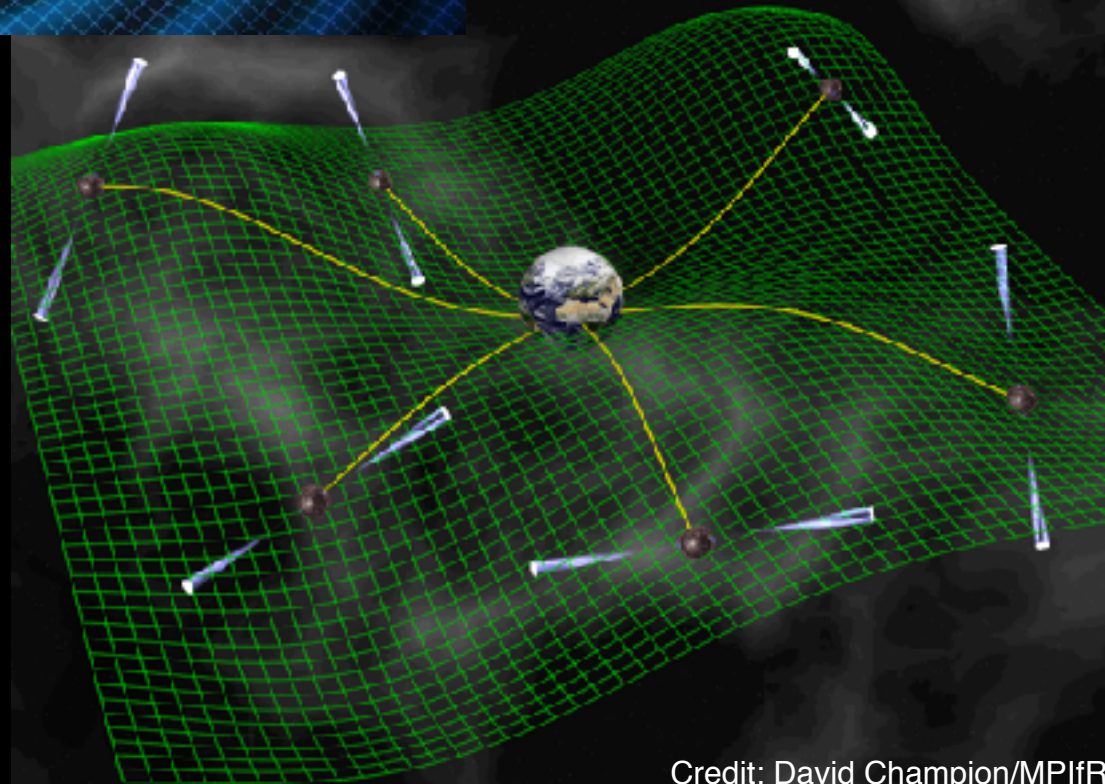
SKA2: Direct imaging of
Cosmic Dawn ($z = 12 - 30$).

SKA1: Direct imaging of
EoR structures ($z = 6 - 12$). Power spectrum of
Cosmic Dawn

Testing Gravity

SKA1: 1st detection of nHz-stochastic gravitational wave background.

SKA2: Gravitational wave astronomy of discrete sources: constraining galaxy evolution, cosmological GWs and cosmic strings.

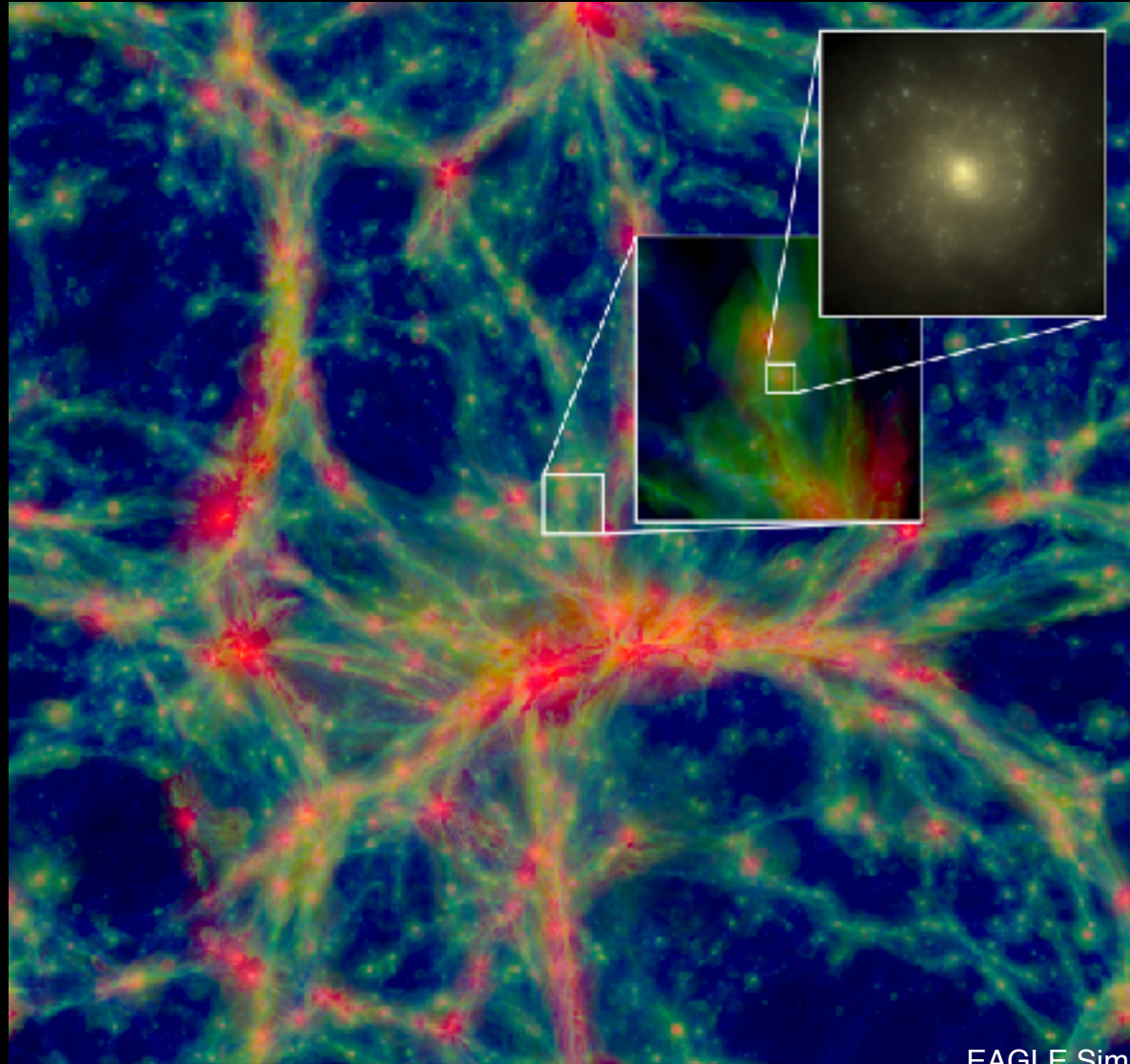


Credit: David Champion/MPIfR

Evolution of Galaxies: HI

SKA1: Gas properties of 10^7 galaxies, $\langle z \rangle \approx 0.3$, evolution to $z \approx 1$, ISM at 50pc resolution to 3Mpc

SKA2: Gas properties of 10^9 galaxies, $\langle z \rangle \approx 1$, evolution to $z \approx 5$, ISM at 50pc resolution to 10Mpc



Evolution of Galaxies: Continuum

Galaxies out to $z \sim 10$

SKA1: Star
formation rates (10
 M_{\odot}/yr to $z \sim 4$)

VLA

SKA2: Star
formation rates (10
 M_{\odot}/yr to $z \sim 10$)

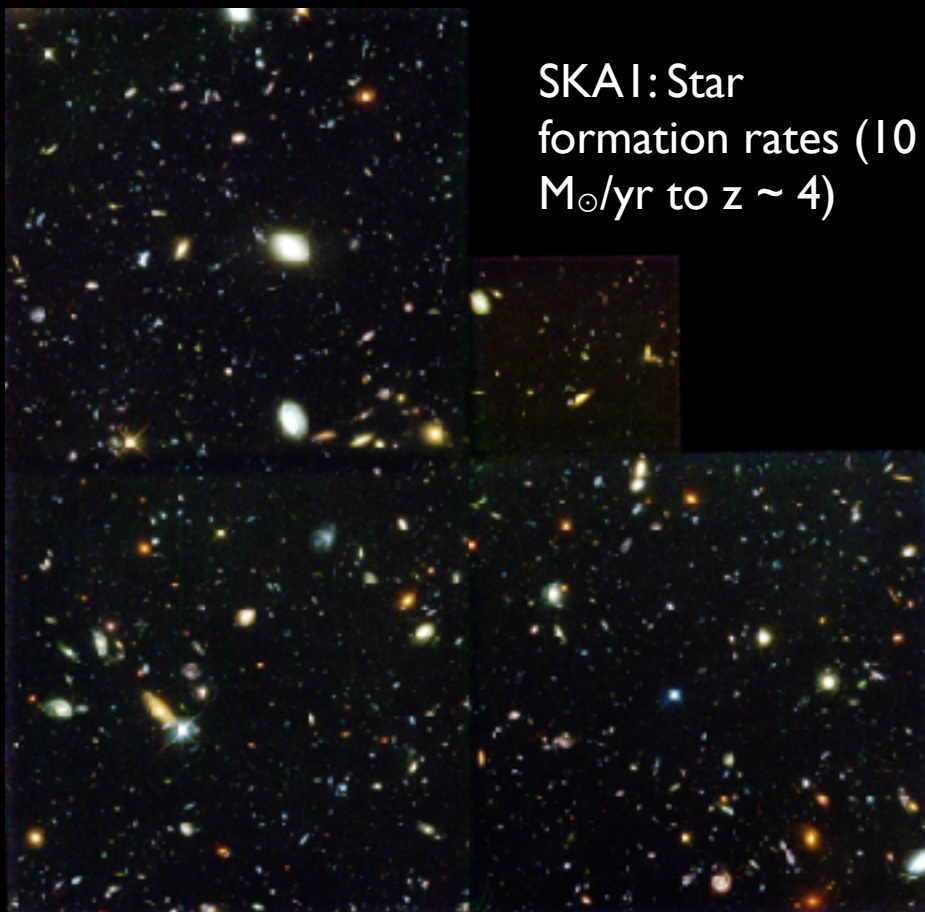


Hubble Deep Field (NASA)

Credit: Paul Alexander (Cambridge)

Evolution of Galaxies: Continuum

Galaxies out to $z \sim 10$



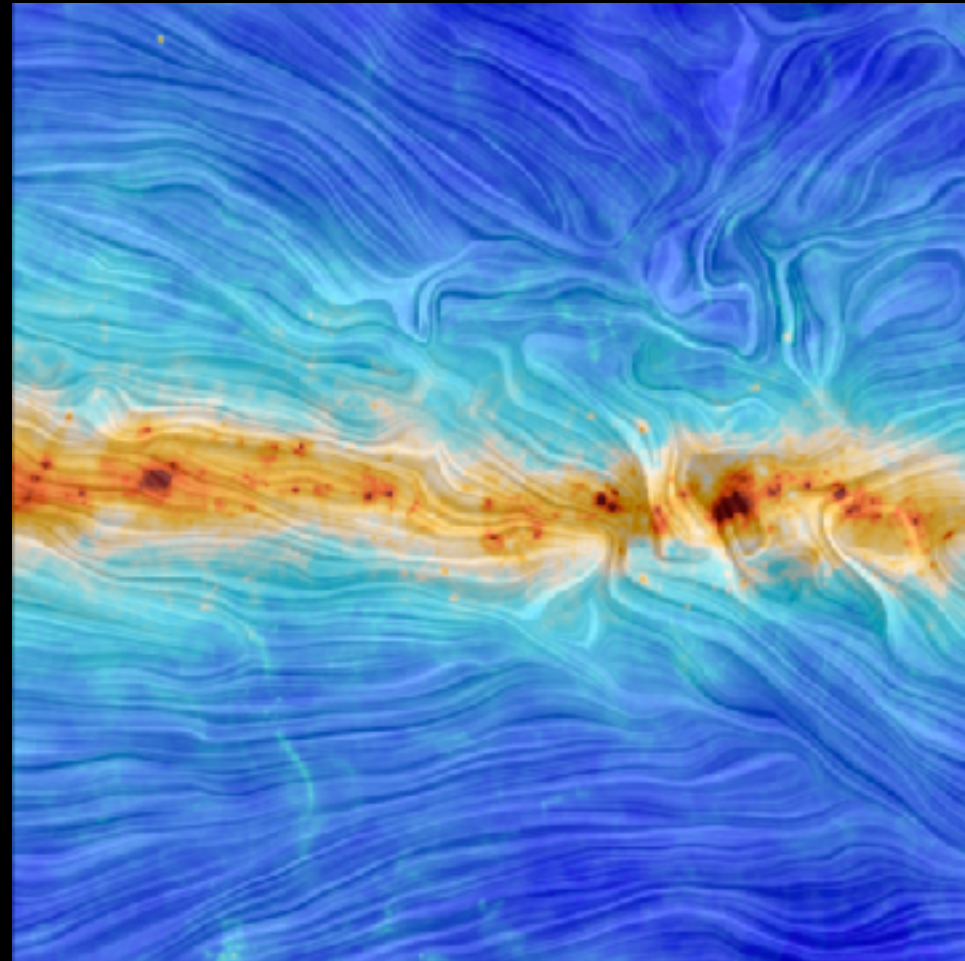
SKA1: Star formation rates ($10 M_{\odot}/\text{yr}$ to $z \sim 4$)



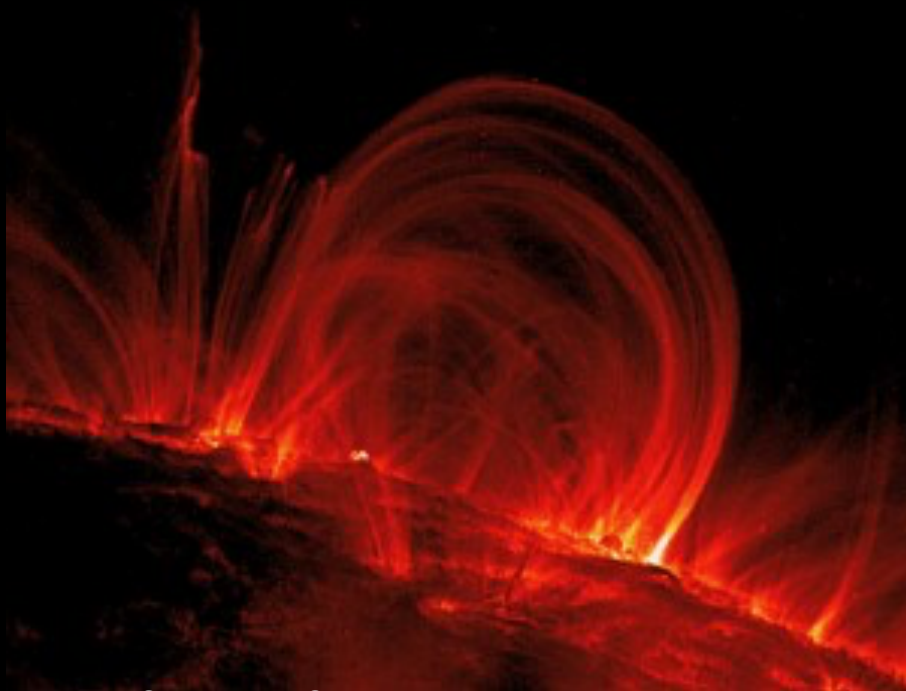
SKA
SKA2: Star formation rates ($10 M_{\odot}/\text{yr}$ to $z \sim 10$)

Cosmic Magnetism

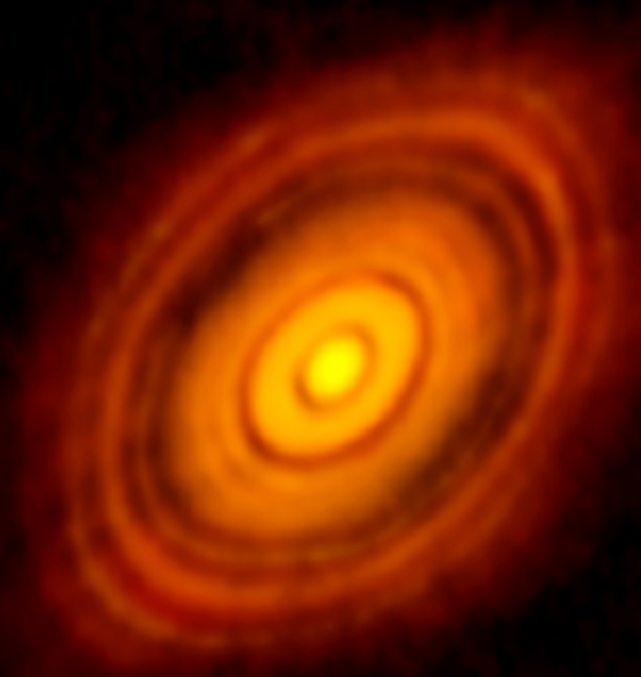
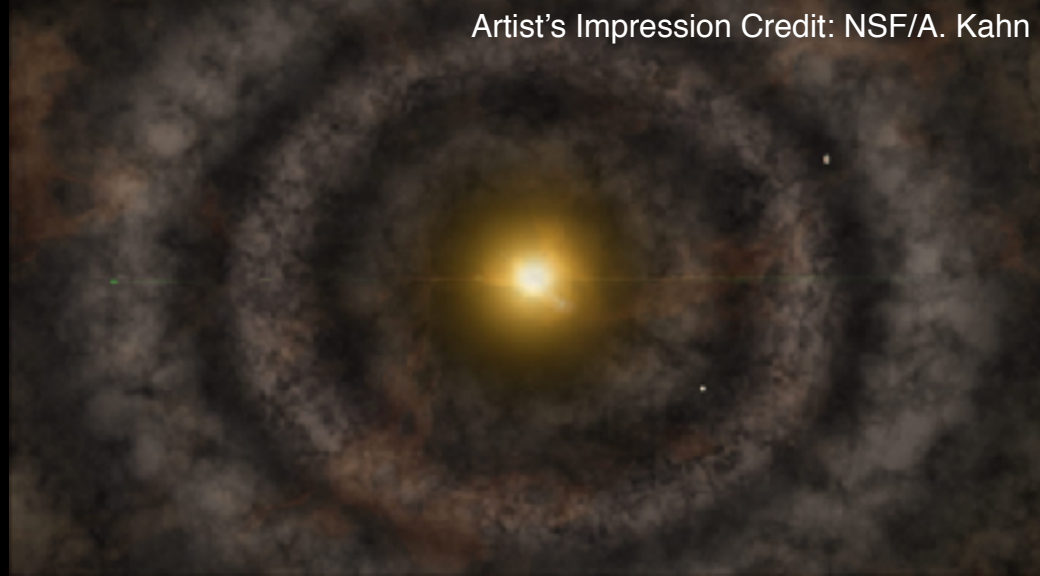
SKA1: The role of magnetism from sub-galactic to Cosmic Web scales, the RM-grid @ 300/deg²



SKA2: The origin and amplification of cosmic magnetic fields, the RM-grid @ 5000/deg²



Cradle of Life



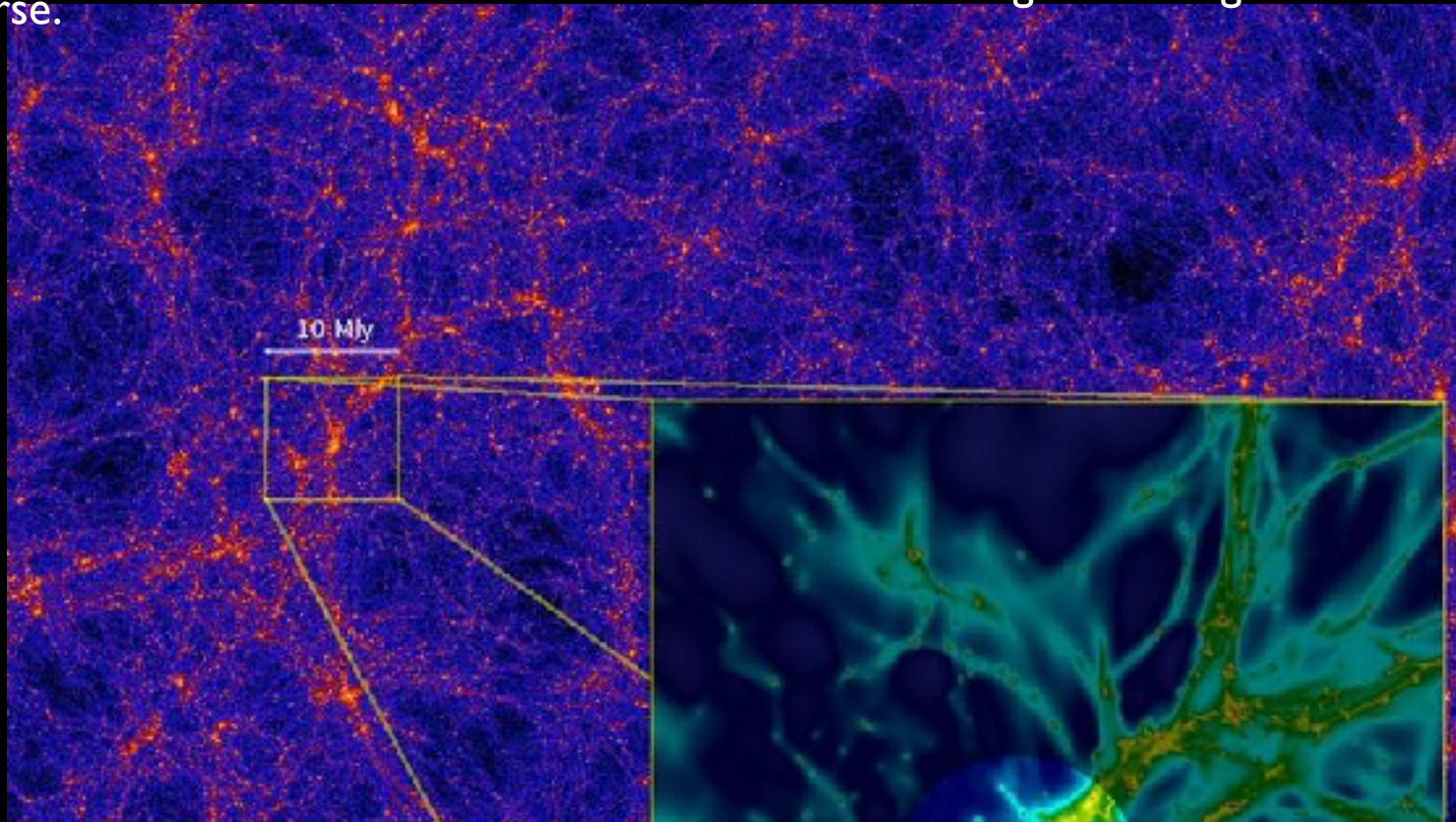
SKA1: Proto-planetary disks;
imaging inside the snow/ice
line (@ < 100pc)

SKA2: Proto-planetary disks;
sub-AU imaging (@ < 150pc)

Things that go bang

SKA1: Use fast radio bursts to uncover the missing "normal" matter in the universe.

SKA2: Fast radio bursts as unique probes of fundamental cosmological parameters and intergalactic magnetic fields.



The enormity of SKA Science



Science WGs

- Current SWGs represent a wide range of scientific areas:
 - Extragalactic Spectral Line (non-HI)
 - Our Galaxy
 - Solar, Heliospheric & Ionospheric Physics
 - Epoch of Reionization
 - Cosmology
 - Extragalactic Continuum (galaxies/AGN, galaxy clusters)
 - Cradle of Life
 - HI galaxy science
 - Magnetism
 - Pulsars
 - Transients
- Technique focused Working Group:
 - VLBI
- Topical Focus Group:
 - High Energy Cosmic Particles

Membership open to any active researcher with willingness to contribute at appropriate level

Anyone can nominate themselves by contacting the current SWG Chairperson (per web site) or SKA Project Scientist/Science Director

A potted history of SKA

- Original idea 1991
- SKA meetings (1993 -)
- SKA Science Book v1 2004
- SKA science - Key Science Projects (2005-ish)
- Site selection 2012
- SKA Phase I Baseline design - 2013
- SKA Phase I cost-cap 650M€ 2013
- Re-baseline 2014/2015 - new SKA1 concept
- SKA Science Book v2 2015
- Deployment baseline at 674M€ 2017
- *SKA1 starts construction 2019*
- *SKA1 early science start around 2022*
- *SKA2 ?*

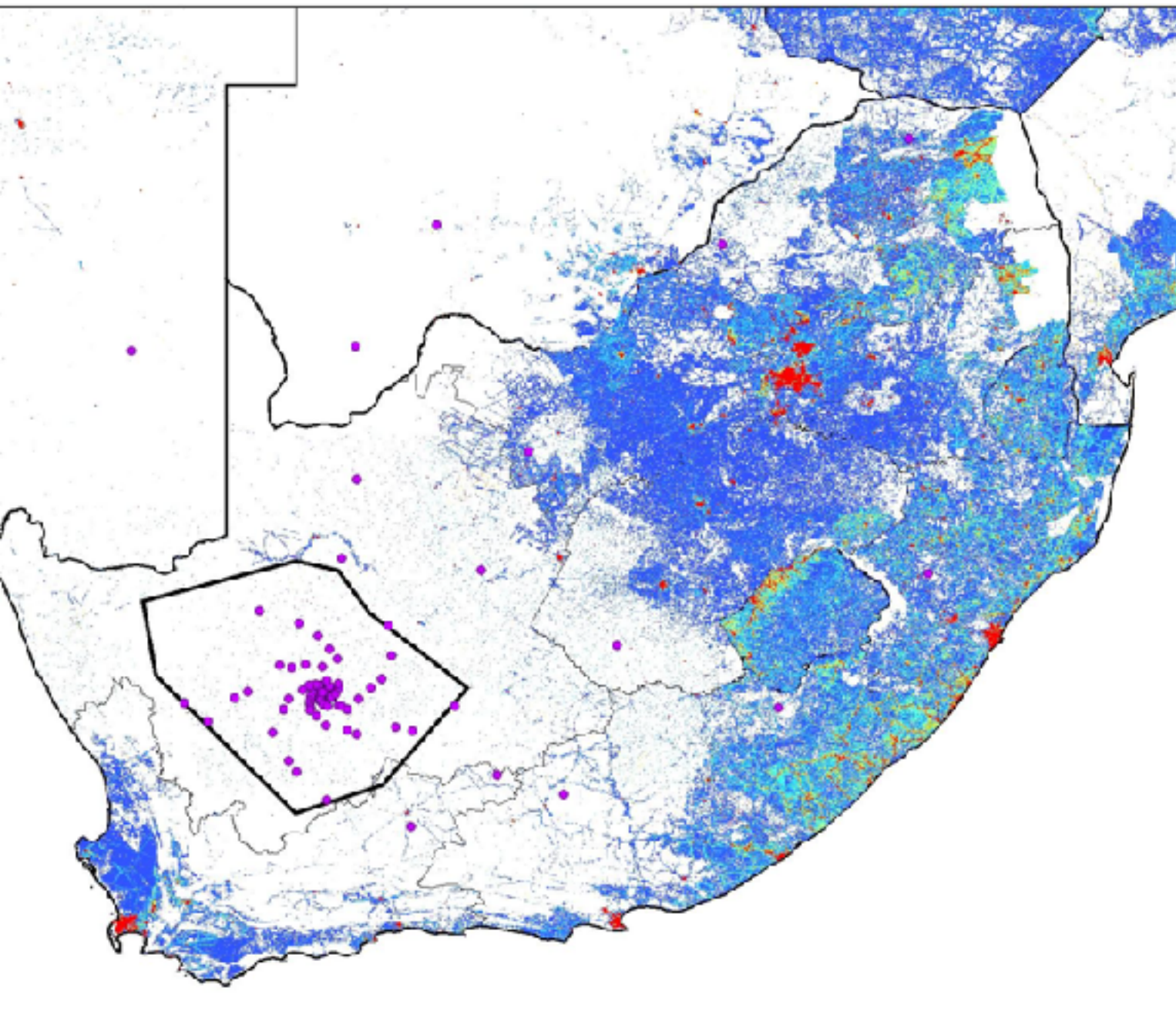
Steps to building the world's biggest telescope...

Select a site...



WWW.SKA.GOV.AU





Legend

● SKA_Configuration_SPDO_Dish_F

● AA1_SPDO_Version1

● AA2_SPDO_Version2

□ KCAAA1

Population

Value

0 - 4 (**< 4 km⁻²**)

4.00000001 - 14

14.00000001 - 29

29.00000001 - 47

47.00000001 - 68

68.00000001 - 91

91.00000001 - 116

116.00000001 - 142

142.00000001 - 169

169.00000001 - 197

197.00000001 - 225

225.00000001 - 255



Contact:
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 Rosebank
 2196
 South Africa
 Tel: +27 11 442 2434
 Fax: +27 11 442 2434
 Email: atiplady@ska.ac.za





Murchison Radio-Astronomy Observatory (MRO)

S26° 42' 15", E116° 39' 32"

Extreme Radio Quietness

Shire of Murchison

Population density: 0.002 km^{-2}

Extreme Radio Quietness

Radio Quiet
Zone

Shire of Murchison

Population density: 0.002 km^{-2}



Two sites...



WWW.SKA.GOV.AU









Two sites...



WWW.SKA.GOV.AU





WWW.SKA.GOV.AU



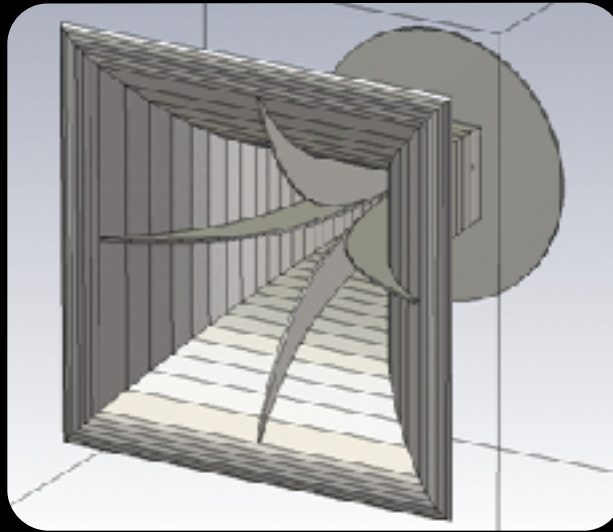




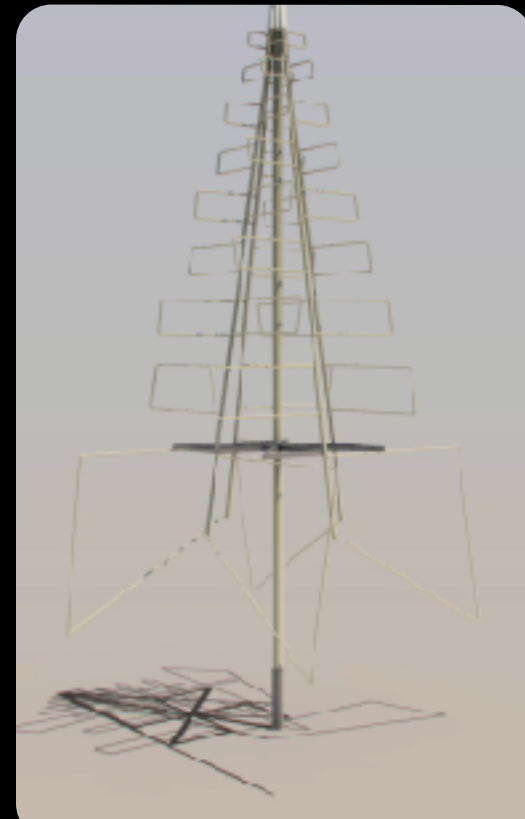
Design what to build...



Credit: SKA SA



Credit: Caltech WBSPF for SKA AIP



Credit: SKAO

SKA Stages

SKA1: 2018-2024



130,000 Low Frequency Aperture Arrays



175 15m dishes

SKA2: 2025+

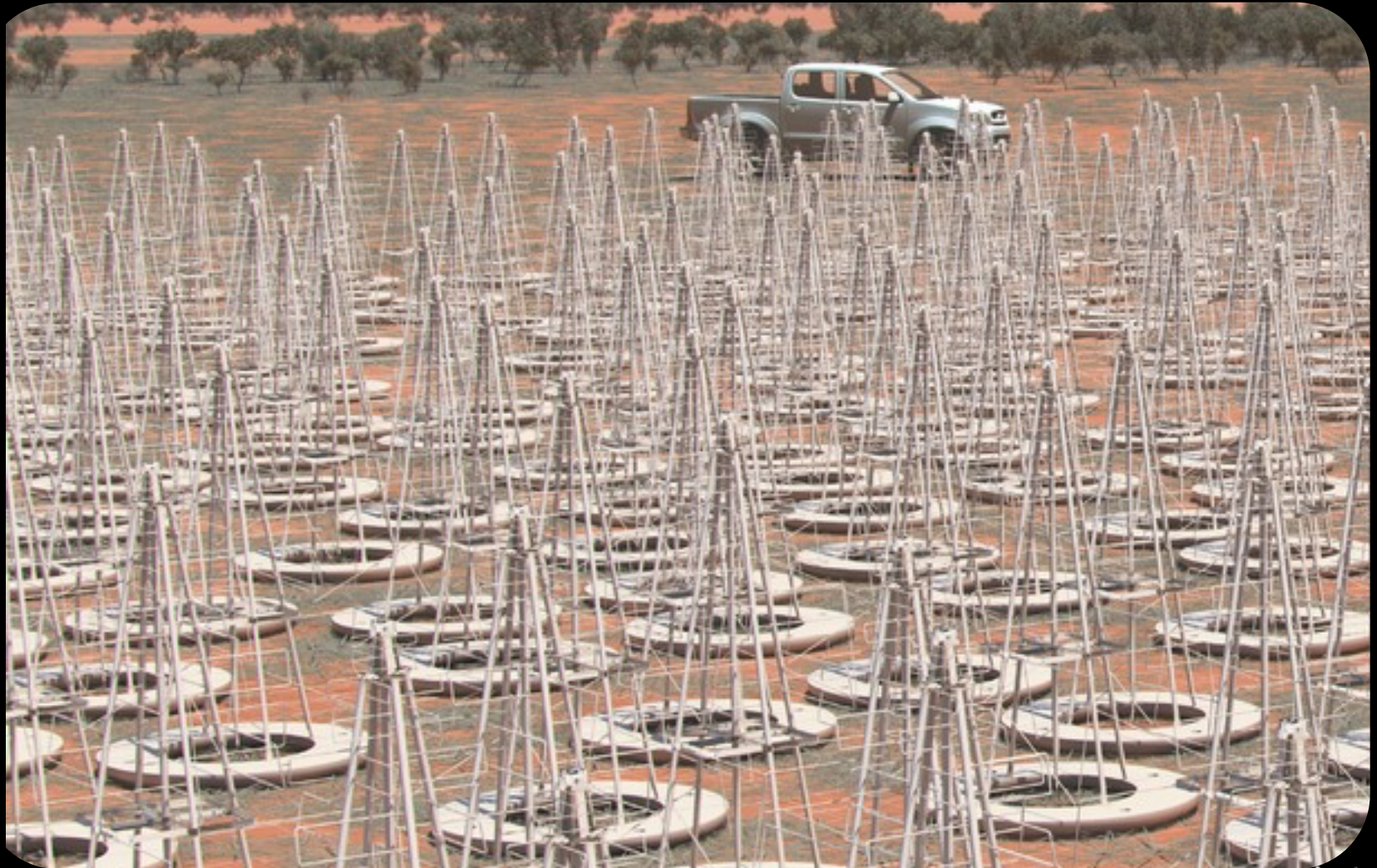


>250,00 LFAA



2500 dishes

SKAI-LOW



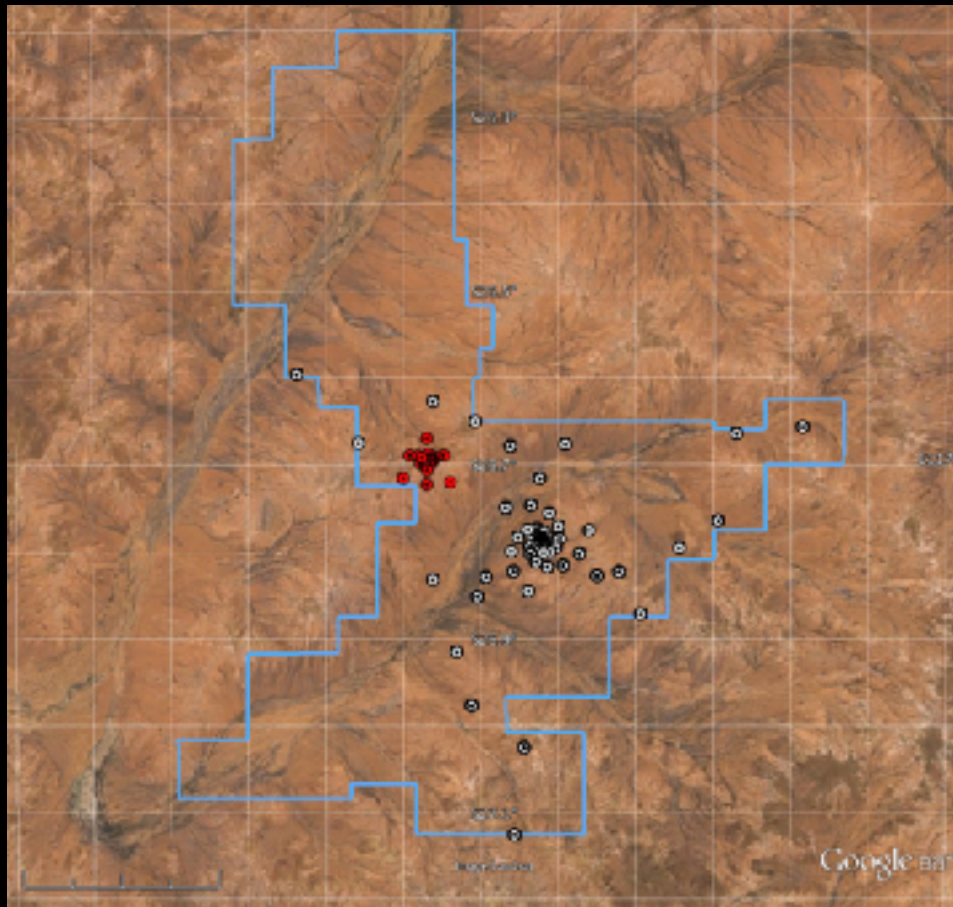
SKA I-LOW



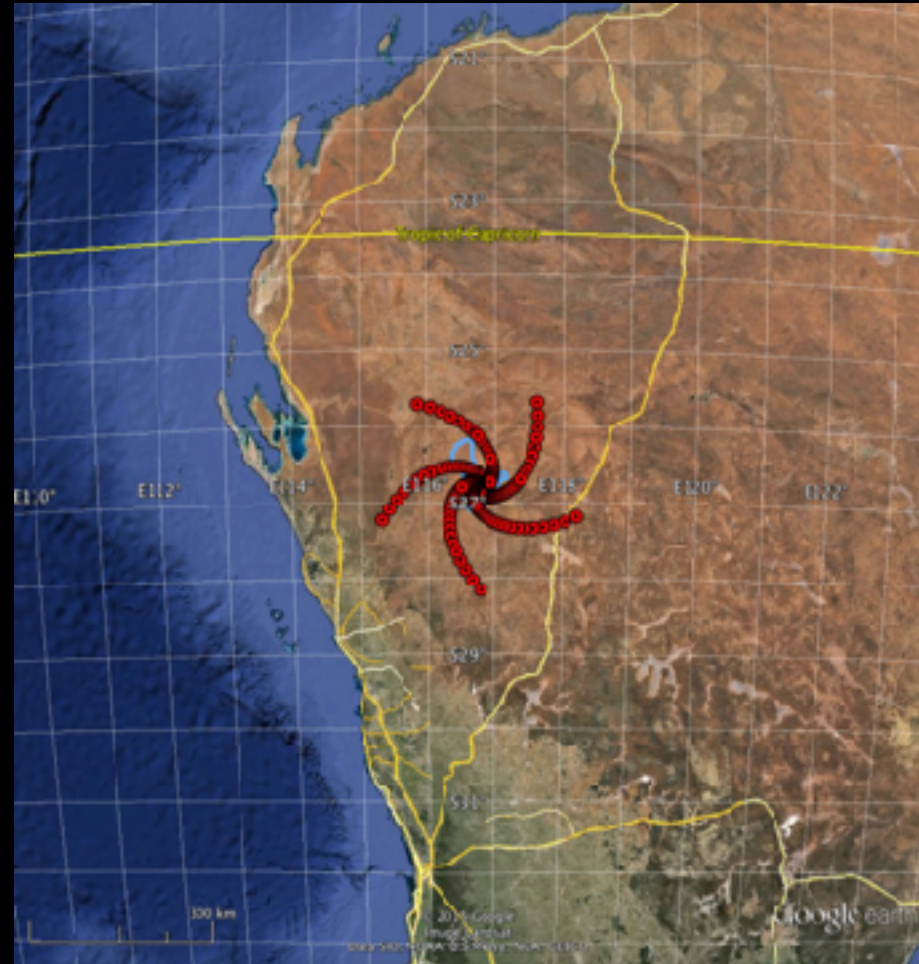
- To be built in Western Australia
- Operate 50 - 350 MHz
- 130,000 elements, 512 stations of 256 antennas
- Maximum baseline ~60-80km (5 arcmin resolution at 100 MHz), centrally concentrated

SKA1-LOW & SKA2-LOW

SKA1-LOW



SKA2-LOW



SKA I-MID

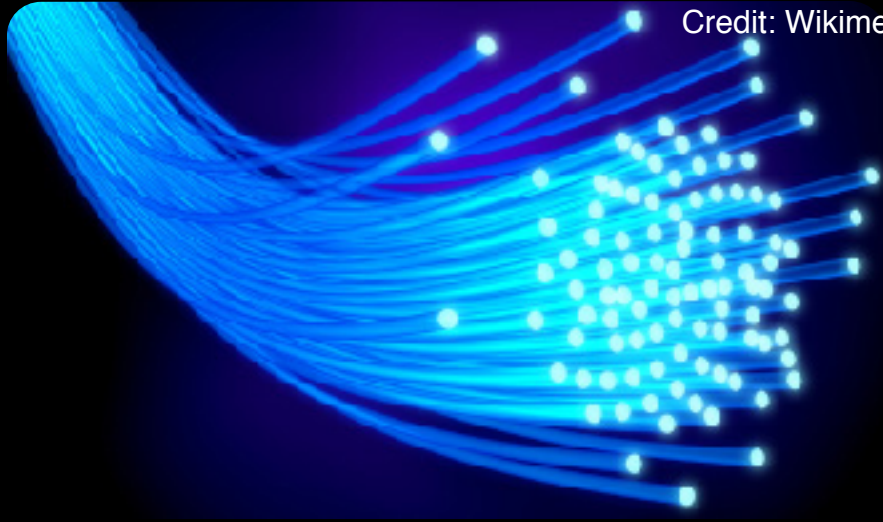


SKA1-MID



- To be built in South Africa
- 133 x 15m antennas plus MeerKAT's 64 x 13.5m antennas
- Three frequency bands: 0.95 - 1.76 GHz (band 2), 4.6 - 14 (24) GHz (band 5), (0.35 - 1.1 GHz (band 1))
- Maximum baseline 150 km (possibly 120km)

Move and crunch the data...



Credit: Wikimedia

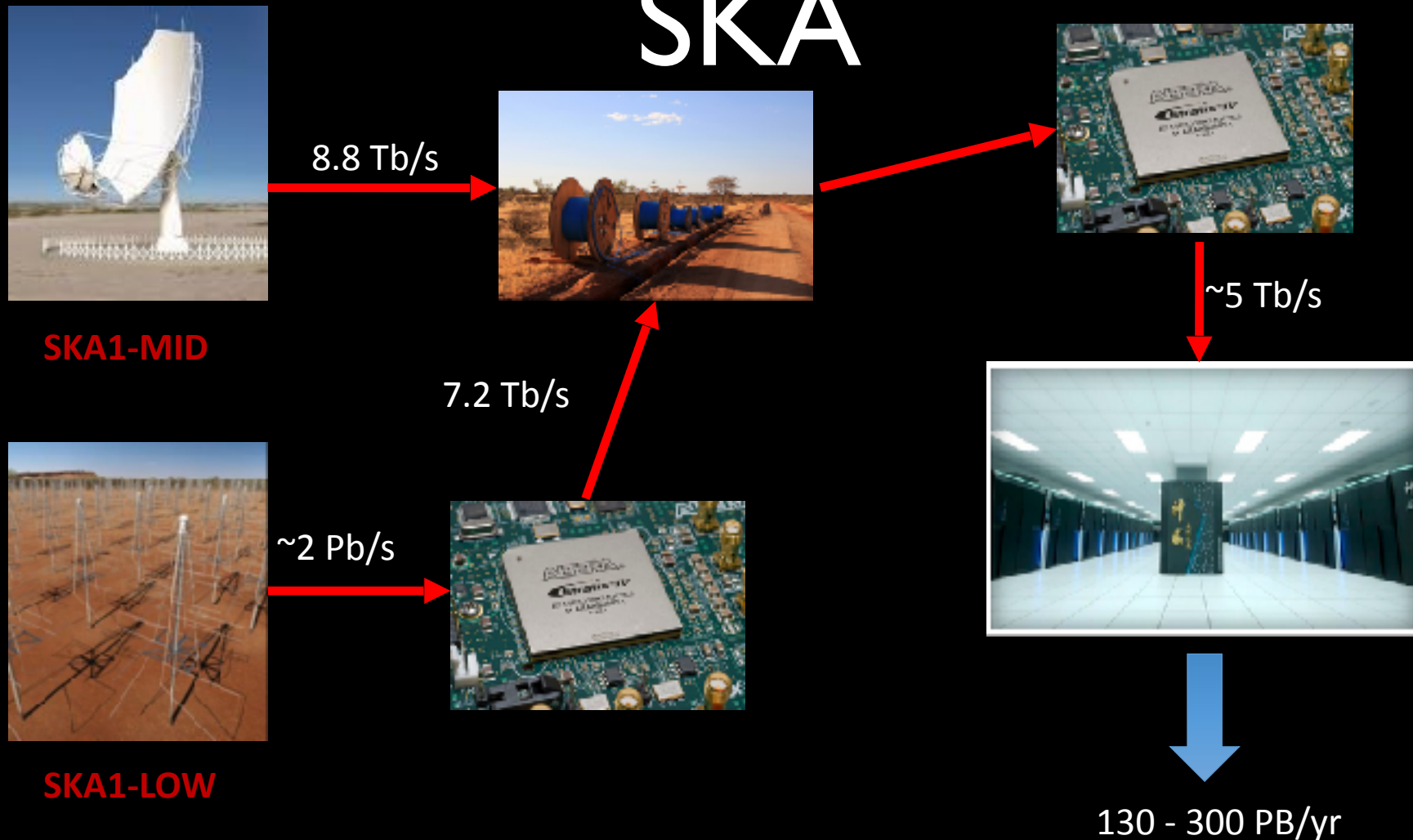


Credit: CSIRO



Credit: IVEC

Data flow through the SKA



SKA1-LOW

Users



Australian National University

How does SKA1 compare with the world's biggest radio telescopes?

SKA1 LOW

Australia
419,000m²
 ~130,000 antennas



MWA
 Murchison Widefield Array, Australia
2,500m²
 2048 antennas

LOFAR
 Low Frequency Array, Europe
52,000m²
 34,000 antennas

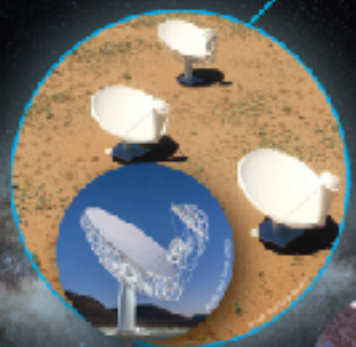
GMRT
 Giant Metrewave Radio Telescope, India
48,000m²
 30 dishes



At 110 MHz
LOW FREQUENCIES

SKA1 MID

South Africa
33,000m²
 ~200 dishes



ASKAP
 Australian Square Kilometre Array Pathfinder, Australia
4,000m²
 36 dishes

MASKA
 Murchison Array, South Africa
9,000m²
 64 dishes

JVLA
 Very Large Array, USA
13,200m²
 27 dishes



MID FREQUENCIES

Lowell
 USA
4,500m²
 78m dish



Effelsberg
 Germany
7,800m²
 100m dish



Parkes
 Australia
3,200m²
 84m dish



GST
 Green Bank Telescope, USA
7,800m²
 100m dish



FAST
 Five-hundred Metre Aperture Spherical Telescope, China
71,000m²
 500m dish



Arecibo
 Puerto Rico
42,000m²
 305m dish



A1MB
 Australia Square Metre Array, Australia
8,500m²
 66 dishes



SINGLE DISHES

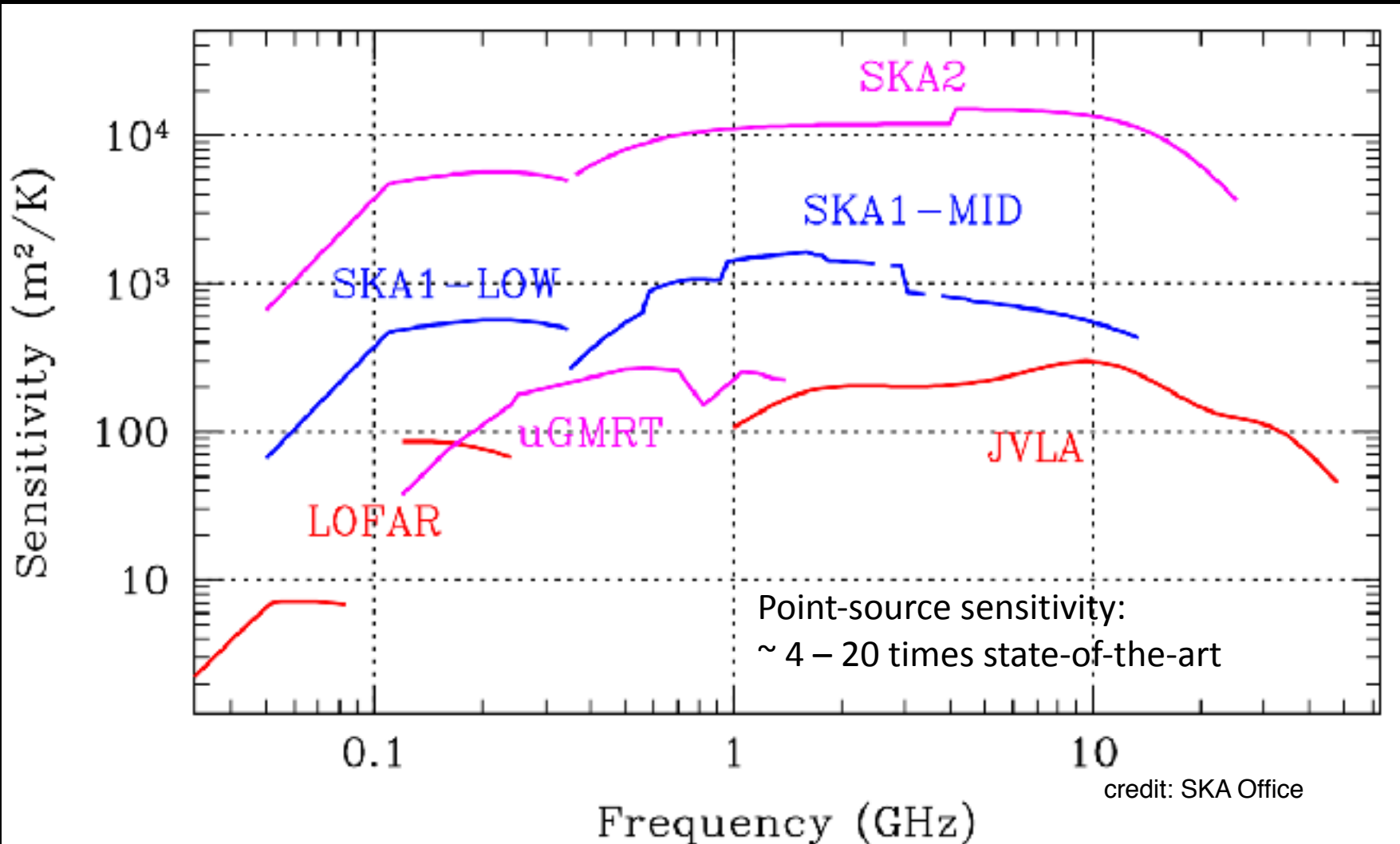
HIGH FREQUENCIES

The Square Kilometre Array (SKA) will be the world's largest radio telescope, revolutionising our understanding of the Universe. The SKA will be built in two phases - SKA1 and SKA2 - starting in 2018, with SKA1 representing a fraction of the full SKA. SKA1 will include two instruments - SKA1 MID and SKA1 LOW - observing the Universe at different frequencies.

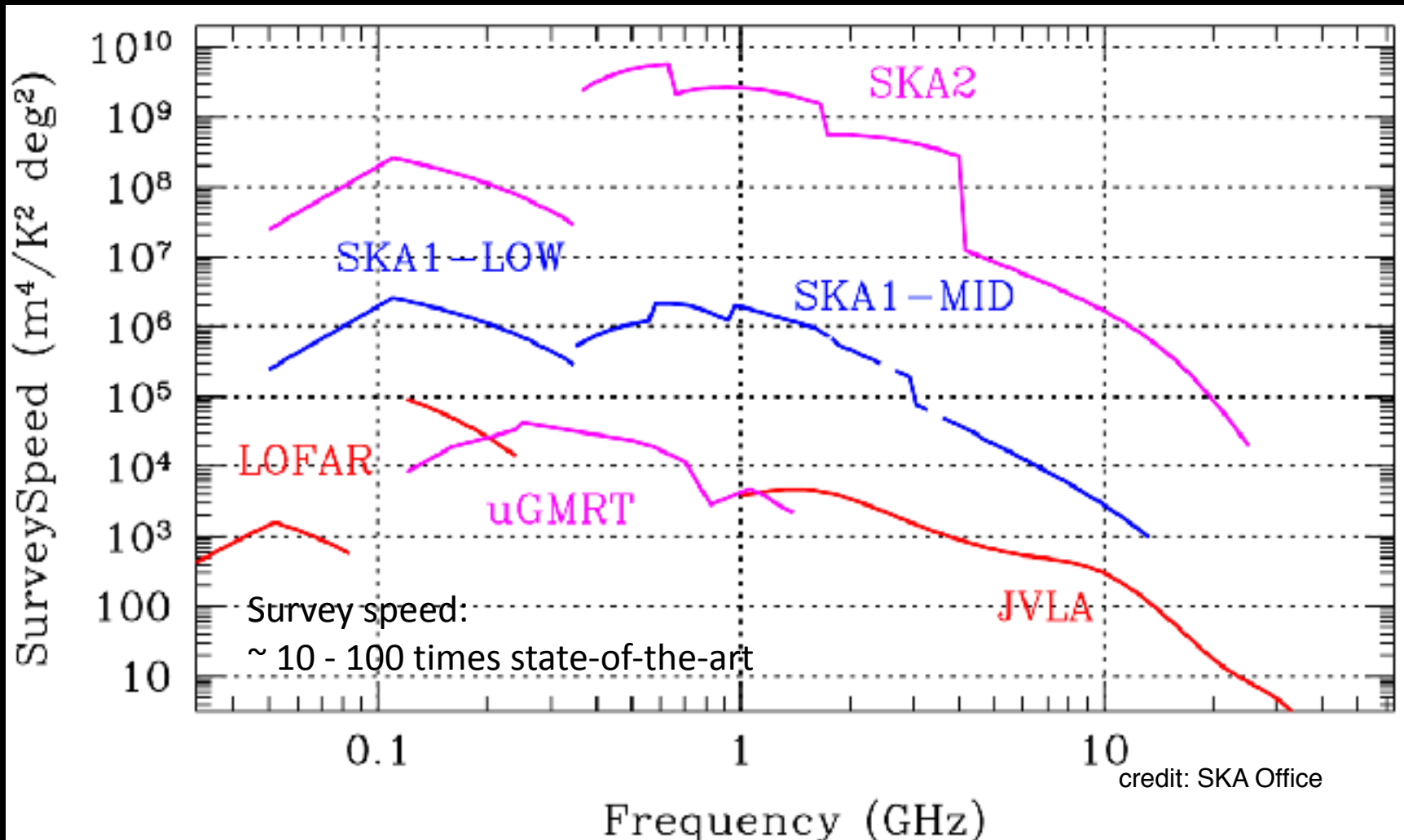
A telescope's capacity to receive faint signals - called sensitivity - depends on its collecting area, the bigger the better. But just like you can't compare radio telescopes and optical telescopes, comparison only works between telescopes working in similar frequencies, hence the different categories above.

The collecting area is just one aspect of a telescope's capability though. Arrays like the SKA have an advantage over single dish telescopes: by being spread over long distances, they simulate a virtual dish the size of that distance and so can see smaller details in the sky, this is called resolution.

Sensitivity Comparison

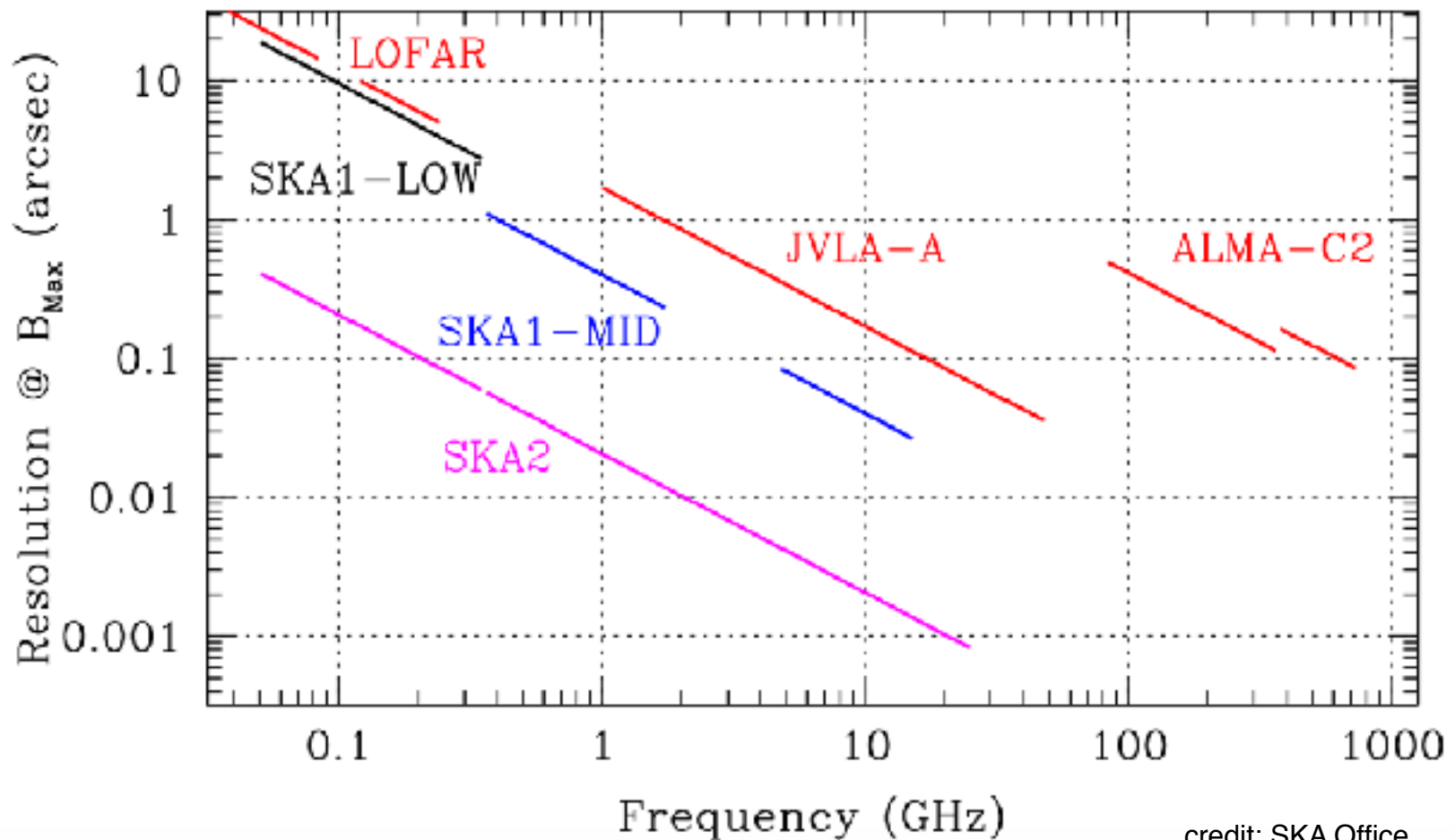


Survey Speed Comp.



credit: SKA Office

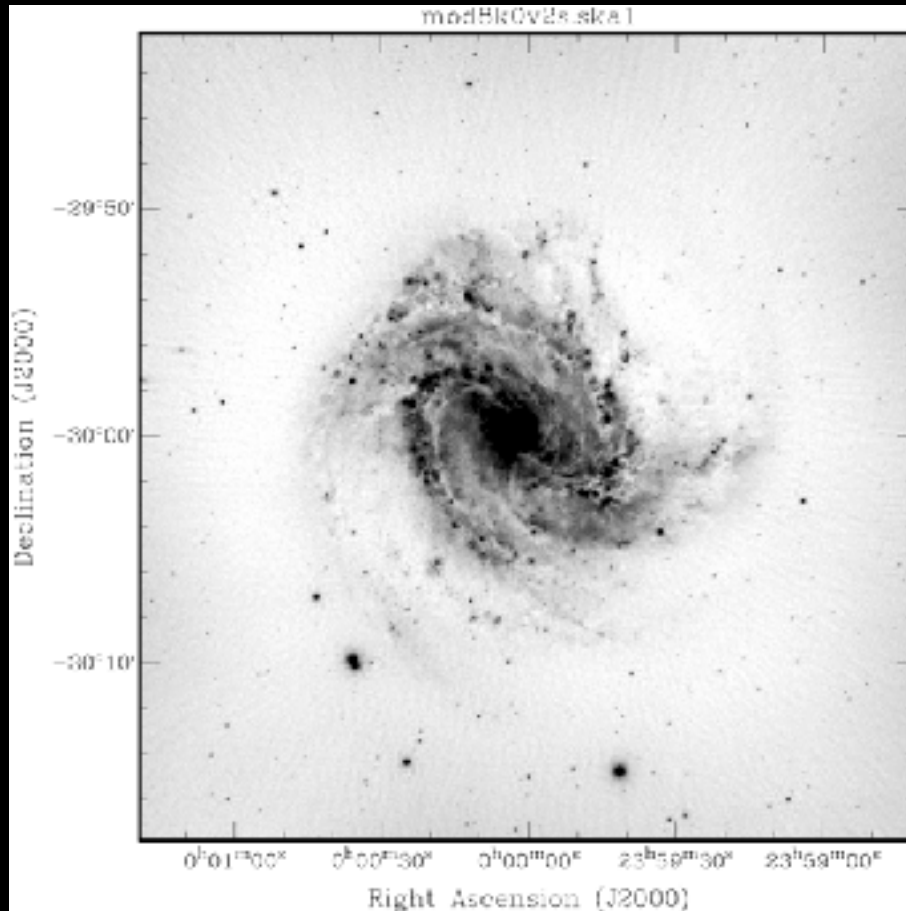
Resolution Comparison



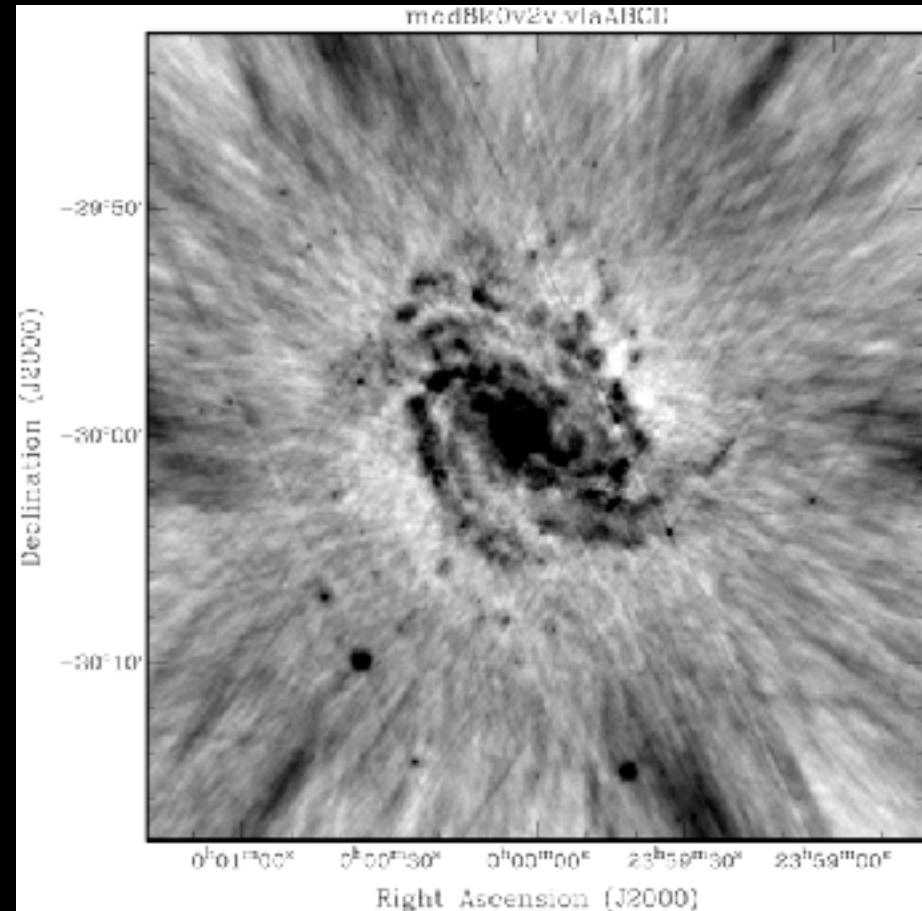
credit: SKA Office

Image Quality Comp

SKA1-Mid snap-shot



VLA A+B+C+D snap-shot



- Single SKA1-Mid snap-shot compared to combination of snapshots in each of VLA A+B+C+D

credit: SKA Office

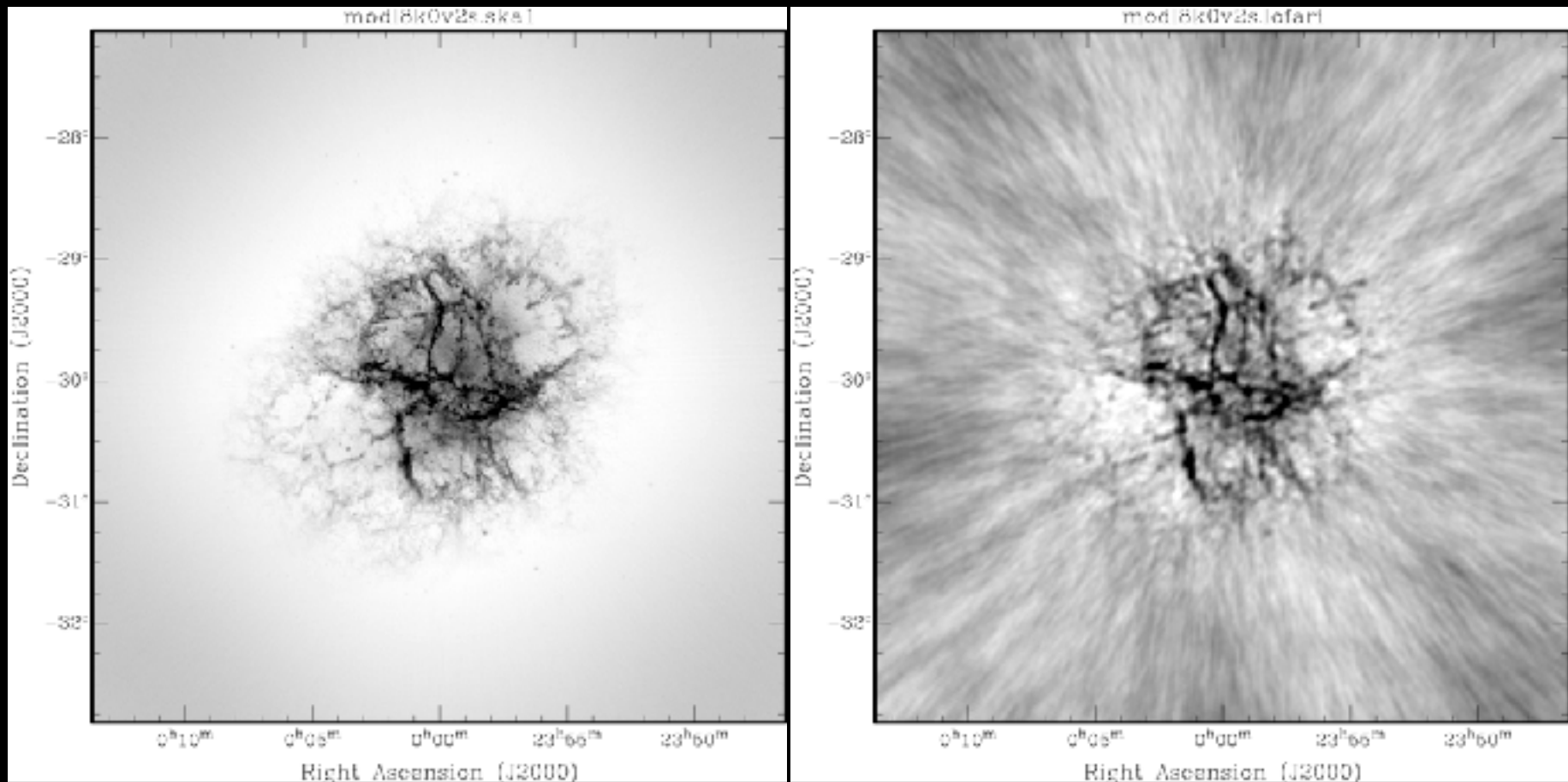


Australian
National
University

Image Quality Comp

SKA1-LOW snap-shot

LOFAR-INTL snap-shot



- Single SKA1-Low snap-shot compared to LOFAR-INTL snap-shot

credit: SKA Office

The first steps...

Murchison Widefield Array



Credit: MWA/ICRAR

Murchison Widefield Array

- 128 tiles
- 80 -300 MHz
- 30 MHz instantaneous BW
- 112 tiles within 1.5 km
- remainder to max baseline 3 km
- Phase II - additional 128 tiles



MeerKAT



MeerKAT



MeerKAT

- 64 dishes
 - 13.m offset gregorian
 - FOV ~ 1 degree
- Frequency bands:
 - 0.90 - 1.67 GHz (now)
 - 0.58 - 1.015 GHz (by mid2018)
 - 1.75 - 3.5 GHz (by late 2018)
- L-band T_{sys}/η : 22 - 24 K!!
- Max baseline: 8 km
 - Min baseline: 29 m
 - 48 antennas (75% of collecting area) in inner 1km



Australian SKA Pathfinder



Credit: Alex Cherney/CSIRO

Australian SKA Pathfinder



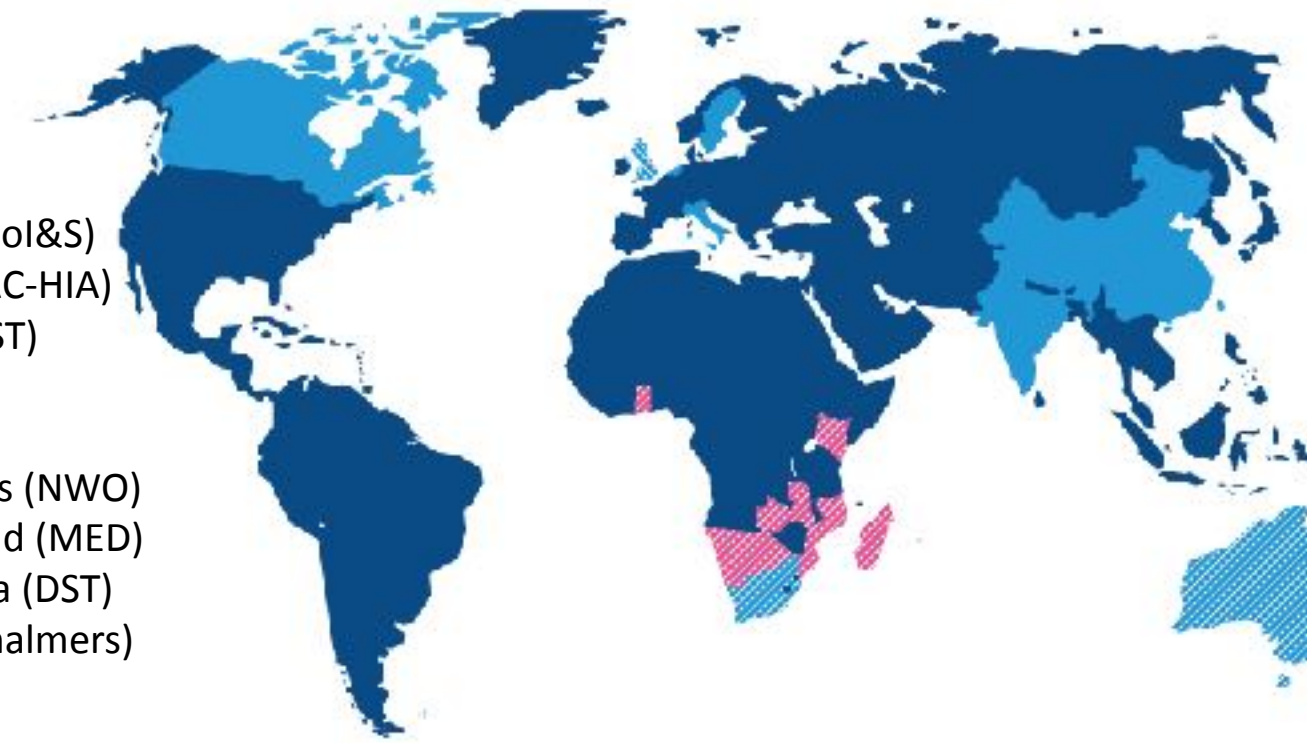
- Thirty-six 12 m antennas
- 30 deg² Field of View
- Frequency range 700 – 1800 MHz
- 6 km max baseline
- $T_{\text{sys}} \sim 80 \text{ K}$

Getting on the SKA plane..



SKA Organisation: 10 countries, more to join

- Australia (DoI&S)
- Canada (NRC-HIA)
- China (MOST)
- India (DAE)
- Italy (INAF)
- Netherlands (NWO)
- New Zealand (MED)
- South Africa (DST)
- Sweden (Chalmers)
- UK (STFC)



Interested Countries:

- France
- Germany
- Japan
- Korea
- Malta
- Portugal
- Spain
- Switzerland
- USA

Contacts:

- Mexico
- Brazil
- Ireland
- Russia



- Full members
- SKA Headquarters host country
- SKA Phase 1 and Phase 2 host countries



- African partner countries (non-member SKA Phase 2 host countries)

This map is intended for reference only and is not meant to represent legal borders





The Exhausting Reality of SKA

Southern
Ocean

South
Atlantic
Ocean

Indian
Ocean

Sunday

leave Saturday

New
Zealand

Australia

South Africa

Madagascar

Namibia

Angola

DR Congo

Tanzania

Kenya

Ethiopia

Nigeria

Chad

Niger

Mali

Libya

Egypt

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Madagascar

Namibia

Angola

DR Congo

Tanzania

Kenya



The Exhausting Reality of SKA



The Exhausting Reality of SKA



Wednesday/Thursday

Monday/Tuesday

Tuesday night

Sunday

leave Saturday

The Exhausting Reality of SKA



Wednesday/Thursday Friday

Monday/Tuesday

Tuesday night

Sunday

leave Saturday

The Exhausting Reality of SKA

Southern Ocean



Wednesday/Thursday Friday

Monday/Tuesday

Tuesday night

Friday night

Sunday

leave Saturday

The Exhausting Reality of SKA

Southern Ocean

Indian Ocean



Wednesday/Thursday Friday

Monday/Tuesday

Tuesday night

Friday night

Sunday

leave Saturday
back Saturday!

The Exhausting Reality of SKA

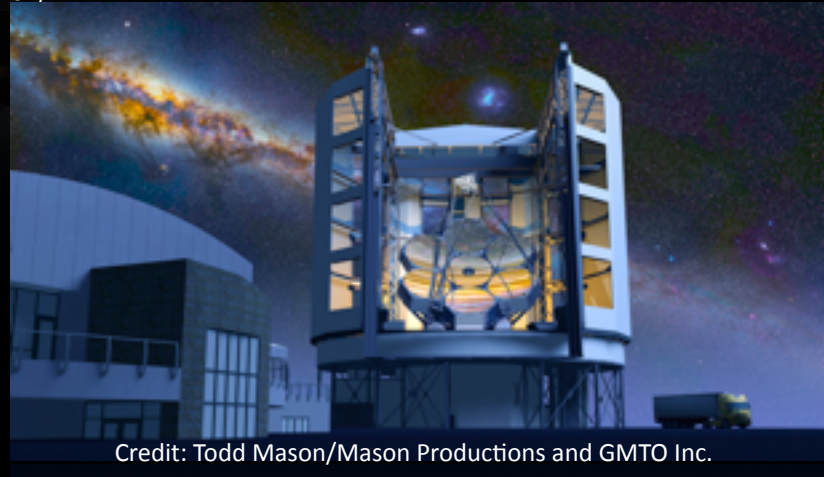
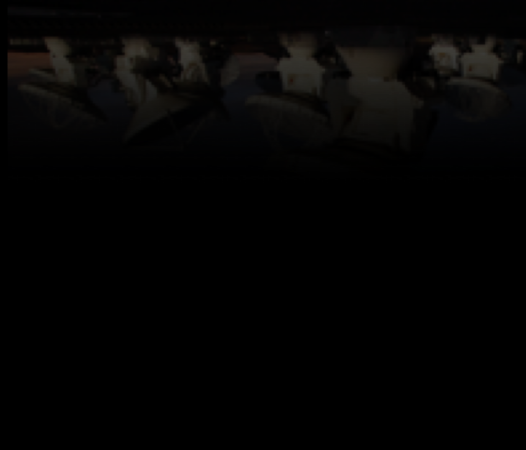
The Great Observatories



Credit: SPDO/TDP/DRAO/Swinburne Astronomy Productions.

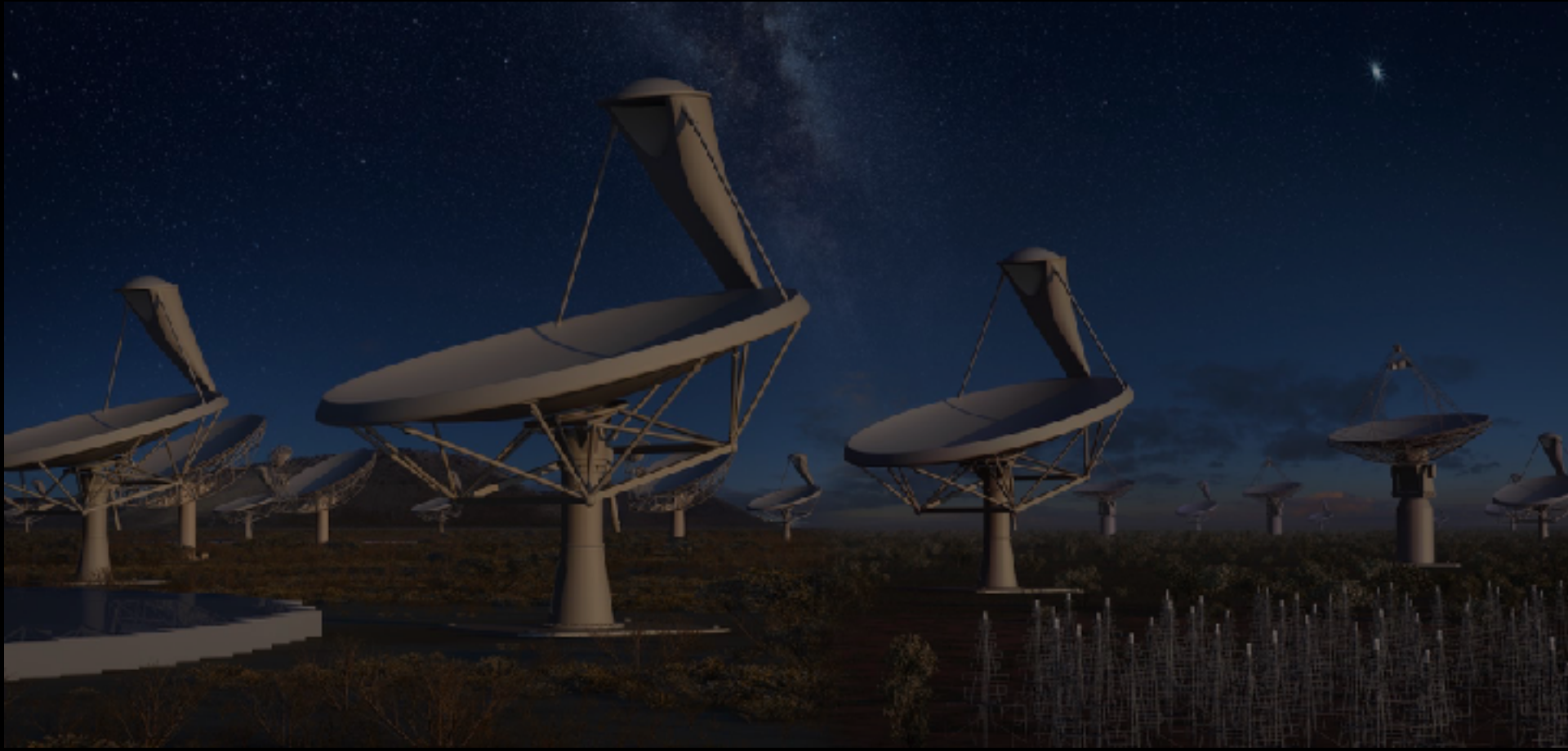


Credit: C. Padilla, NRAO/AUI/NSF)



Credit: Todd Mason/Mason Productions and GMTO Inc.

SKA To Do:



SKA To Do:

- Design it...

SKA To Do:

- Design it...
- Build it...

SKA To Do:

- Design it...
- Build it...
- Use it!