

The Songs of our Universe

(listening as we speak)

COSMIC RADIO SIGNALS DETECTED

COSMIC WHITE NOISE

PULSAR (PSR J1810+17)



PERIODIC PULSAR EMISSION
PERIOD = 1.337 seconds

The Most Ambitious Radio Astronomy Endeavour of the 21st Century?

Science, Technology and Engineering Dialogues in a Large-scale Project

talk first prepared for GlobalEM 2024

Howard Reader

Emeritus Professor, Stellenbosch University, EE Engineering
Former South African URSI Commission E Chair
MESA Solutions, South Africa

Background to original presentation

Presentation – summarized RSA efforts, with **Electromagnetic Compatibility** (EMC) emphasis

- “Few projects come close to scope and ambition of Square Kilometre Array (SKA) as a scientific endeavour
 - How can we fill in gaps in our understanding of Universe by reading its history as written in language of its most abundant constituent, Hydrogen?”
- Observation of **Hydrogen** line (H1), pulsars (cosmic ticking clocks), **Cosmic Microwave Background** (CMB) is severely constrained by Electromagnetic (EM) activity of our modern living

Early Perspectives

- Phil Diamond (DG) at 2013 SKA Bursars’ Conference: self-generated **Radio Frequency Interference** (RFI) to be addressed vigorously at every stage of project
- SKA spawned from RA 1990 – so vision more in ‘science’ than in ‘technology’. Science before technology?
- Technology before science? PJ Hall: “The SKA – an engineering perspective (2005)”

Background on original presentation +

- Decision in 2012 to co-locate SKA, splitting it in phases.
- 2021 Nature article, Phil Diamond indicated 2,000 parabolic dishes and up to one million arrayed antennas
 - sensitivity to listen to origins of our universe.
- First phase cost just under US\$2.4 billion to build and operate, a decade to complete:
 - will form about 10% of the final design,
 - nearly 200 dishes in South Africa, and
 - more than 130,000 antennas in stations of 512 in Australia

SKA and Other Mega-science Projects

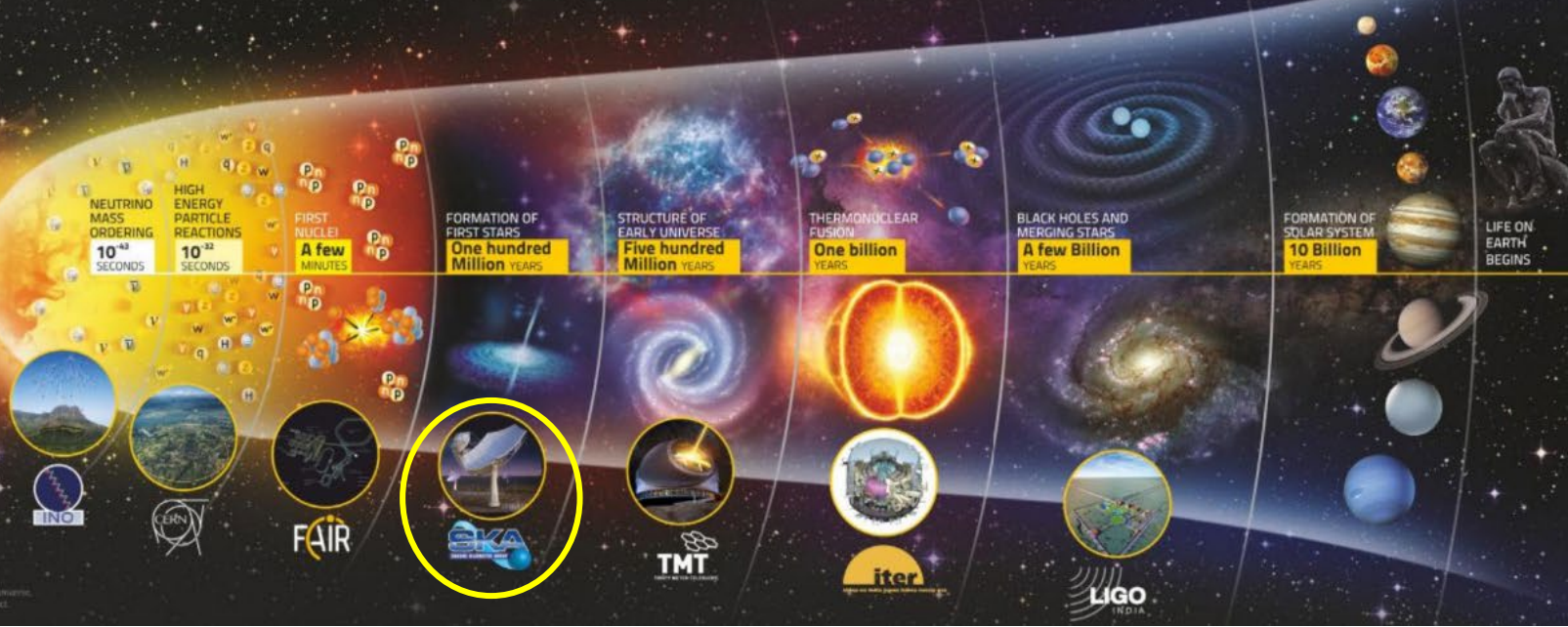


From micro to macro: Understanding the universe through mega science projects



The image shows the different mega-projects being represented in the exhibition along with the science areas they will address in the context of the history of our Universe. The SKA appears prominently in the list along with other experiments involving astronomy telescopes and high energy physics instruments.

BIG BANG



- Interesting depiction from India's first global Mega-Science Exhibition, 2019
- SKA to probe back to first 100 Million years; includes **Epoch of Reionisation (EoR)** – somewhere around first 1 Gyr
 - Observe H1 line for time estimates (EoR: 50 – 70 MHz)

Mathematician Jordan Ellenberg created Hawking Index (2014), after Hawking's *A Brief History of Time* - was considered **most unread bestseller at the time**

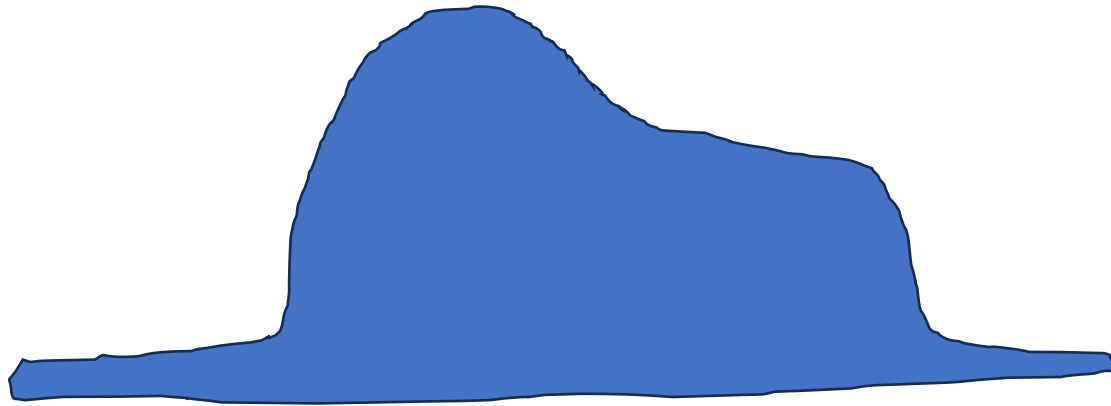
In Acknowledgement of Book

- Where did the Universe come from?
- How and why did it begin?
- Will it come to an end, and if so, how?
- These are the questions that are of interest to us all. But modern science has become so technical that only a very small number of specialists are able to master the mathematics used to describe them.
- Yet the basic ideas about the origin and fate of the Universe can be stated without mathematics in a form that people without scientific education can understand. This is what I have attempted to do....

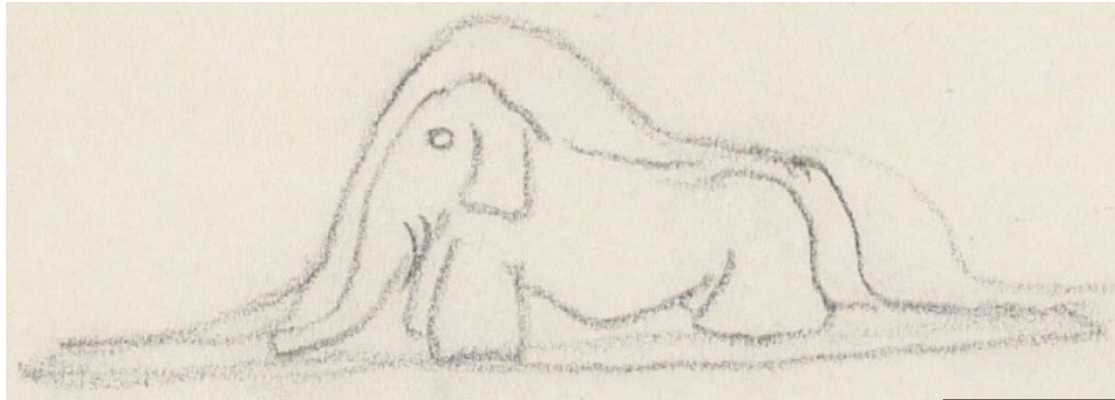
Someone told me that each equation I included in the book would halve the sales. I therefore have resolved not to have any equations at all.

In the end, however, **I did put in one equation**, namely Ein's

What do you see?



Antoine de Saint-Exupéry: Le Petit Prince



The
Morgan
Library &
Museum

How do you visualize communication between moving vehicles?



How Could WWI
Telegraphy in
Trenches only
use 1 Wire?



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Branley Coherer

part of a personal interest leading to electronic engineering

connected to our ability to look into space



Let's reflect on our language frameworks

Humanities/Philosophy (co-pilot opinion)

Paradigm

Reductionism

Knowledge

Types of rationality

Empiricism

Experience

Modernism

Postmodernism

Arguments

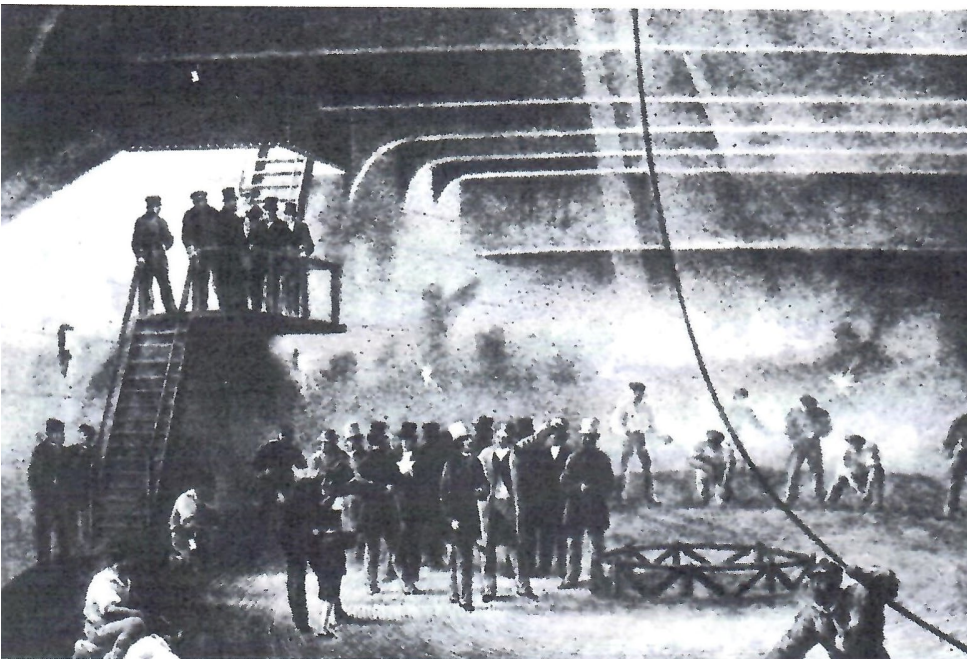
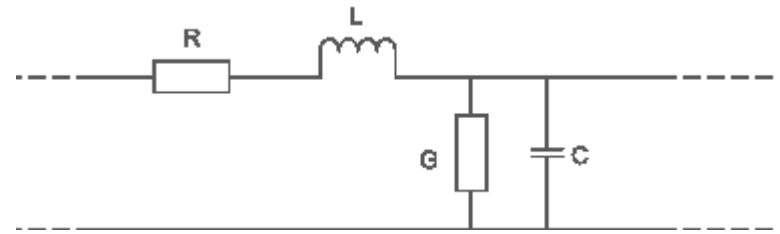
Causality

Electrical/Electronic Engineering

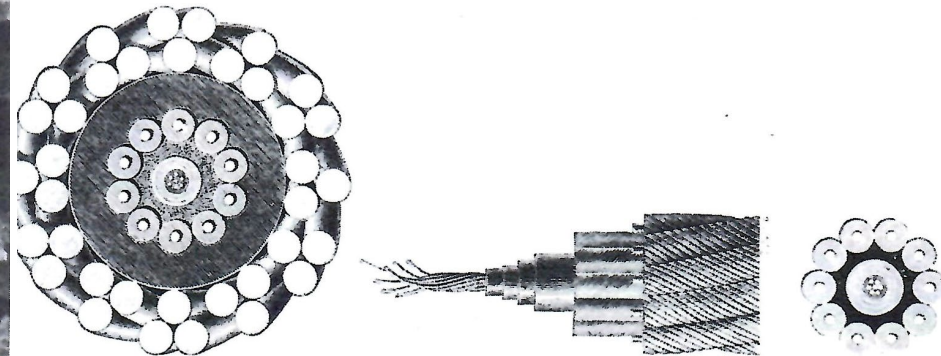
- **Voltage:** Electric potential difference between two points.
- **Current:** Flow of electric charge, Amperes (A).
- **Resistance:** Opposition to flow of current, Ohms (Ω).
- **Capacitance:** Ability of a system to store electric charge, Farads (F).
- **Inductance:** Ability of a system to store magnetic field, Henrys (H).
- **Power:** Rate at which electrical energy transferred by an electric circuit, Watts (W).
- **Frequency:** Cycles per second in an alternating current (AC) signal, Hertz (Hz).

Lord Kelvin (William Thomson) and Trans-Atlantic Cable

Oliver Heaviside added in the crucial missing L.



Loading the 1865 cable (2233 miles long, weighing 5000 tons) into the *Great Eastern*, five times larger than any other ship then afloat.



The cables of 1865 and 1866. The cross-sectional view on the left is of the extra-strong shore end, and the middle and right views are of the main ocean section. The seven-strand copper core was covered by four layers of gutta-percha, wrapped in tarred hemp and protected by ten steel wires, each wrapped in impregnated hemp.

Many thanks to Prof Johannes Cloete for tracking this history

Rev Prof David Wilkinson

British Methodist minister, theologian and astrophysicist. Professorship at Durham. Work focuses on the intersection of science and religion

“My background in theoretical astrophysics and one of the big questions for me was the profound question, Twinkle Twinkle Little Star, how I wonder what you are?

The trouble with astrophysicists is that you then might reply

Up above the world so high, a contracting ball of hot hydrogen gas, undergoing nuclear fusion...

is not quite as catchy as the nursery rhyme, or as beautiful as the poetry or music we've already heard in this service.”

Worked on questions of star formation Galaxy evolution and origin of the universe. First thing – universe is a pretty big place. Just how big the universe is, is not trivial.

Radio waves from Andromeda Galaxy detected in 1949, close neighbour to our own Milky Way. Close?

- It light takes over 2 million years to reach us.
- Sunlight takes 8 min.

Andromeda Galaxy is made up of 100 billion stars as large as Sun. It is one of 100 billion galaxies. So how many twinkling stars are there in the universe? Easy, multiply a 100 billion by a 100 billion and the answer is, a lot.

No wonder Sir Bernard Lovell spoke of us being in [the centre of immensities](#).

Psalmist, who didn't have the advantage of telescope, but did have the advantage of no light pollution: “the heavens declare the glory of God”.

2nd insight from Astrophysics is that universe is intelligible. Observations of other-worldly objects, such as powerful radio sources (quasars) from centre of Galaxy's and even Big Bang echo CMB radiation.

Extraordinary thing that, through observation and mathematics, we can understand phenomena beyond our experience on Earth. Einstein: most incomprehensible thing about the universe, is that it is comprehensible.

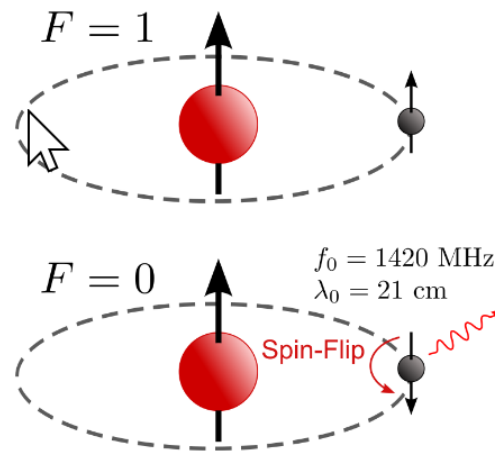
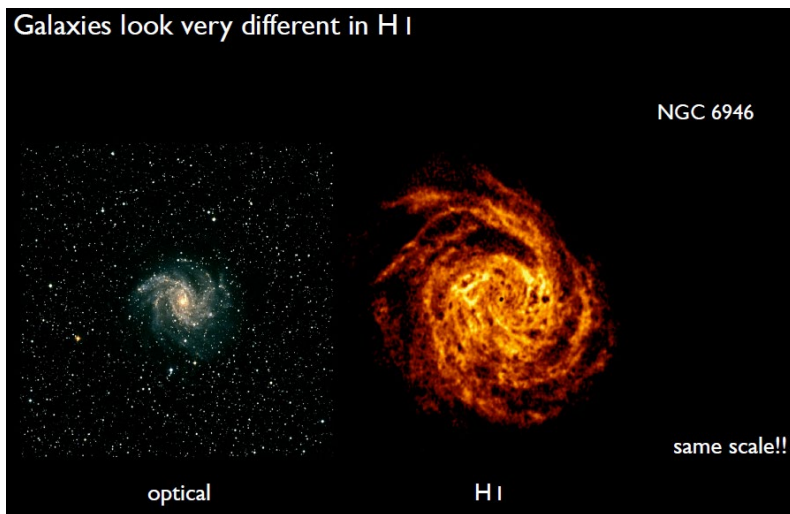
These are not insights that prove the existence of God. The science itself can neither prove nor disprove the existence of a creator or, perhaps more importantly, give us a sense of the nature of that creator.

Two SKAO Science Goals and EMI Consequences

	SKA1	SKA2
The Cradle of Life & Astrobiology Hoare, M. et al. 2015 PoS(AASKA14)115	Proto-planetary disks; imaging snow/ice line (@ < 100pc), Searches for amino acids.	Proto-planetary disks; sub-AU imaging (@ < 150 pc), Studies of amino acids.
	Targeted SETI: airport radar 10^4 nearby stars.	Ultra-sensitive SETI: airport radar 10^5 nearby star, TV ~ 10 stars.
Strong-field Tests of Gravity with Pulsars and Black Holes Kramer, M. & Stappers, B. 2015 PoS(AASKA14)036	1st detection of nHz-stochastic gravitational wave background.	Gravitational wave astronomy of discrete sources: constraining galaxy evolution, cosmological GWs and cosmic strings.
	Discover and use NS-NS and PSR-BH binaries to provide the best tests of gravity theories and General Relativity.	Find all $\sim 40,000$ visible pulsars in the Galaxy, use the most relativistic systems to test cosmic censorship and the no-hair theorem.
The Origin and Evolution of Cosmic Magnetism Johnston-Hollitt, M. et al. 2015 PoS(AASKA14)092	The role of magnetism from sub-galactic to Cosmic Web scales, the RM-grid @ $300/\text{deg}^2$.	The origin and amplification of cosmic magnetic fields, the RM-grid @ $5000/\text{deg}^2$.
	Faraday tomography of extended sources, 100pc resolution at 14Mpc, 1 kpc @ $z \approx 0.04$.	Faraday tomography of extended sources, 100pc resolution at 50Mpc, 1 kpc @ $z \approx 0.13$.
Galaxy Evolution probed by Neutral Hydrogen Staveley-Smith, L. & Oosterloo, T. 2015, PoS(AASKA14)167	Gas properties of 10^7 galaxies, $\langle z \rangle \approx 0.3$, evolution to $z \approx 1$, BAO complement to Euclid.	Gas properties of 10^9 galaxies, $\langle z \rangle \approx 1$, evolution to $z \approx 5$, world-class precision cosmology.
	Detailed interstellar medium of nearby galaxies (3 Mpc) at 50pc resolution, diffuse IGM down to $N_{\text{H}} < 10^{17}$ at 1 kpc.	Detailed interstellar medium of nearby galaxies (10 Mpc) at 50pc resolution, diffuse IGM down to $N_{\text{H}} < 10^{17}$ at 1 kpc.

Why H1 Line?

With thanks: Tom Osterloo, ASTRON



- Atomic H photon emission with spin flip of lowest state
- $1420.4058 \text{ MHz} = 21.106 \text{ cm}$
- One flip 10^7 yrs, but 10^{66} NH atoms in a typical spiral galaxy!
(Photo UCLA Astrophysics)

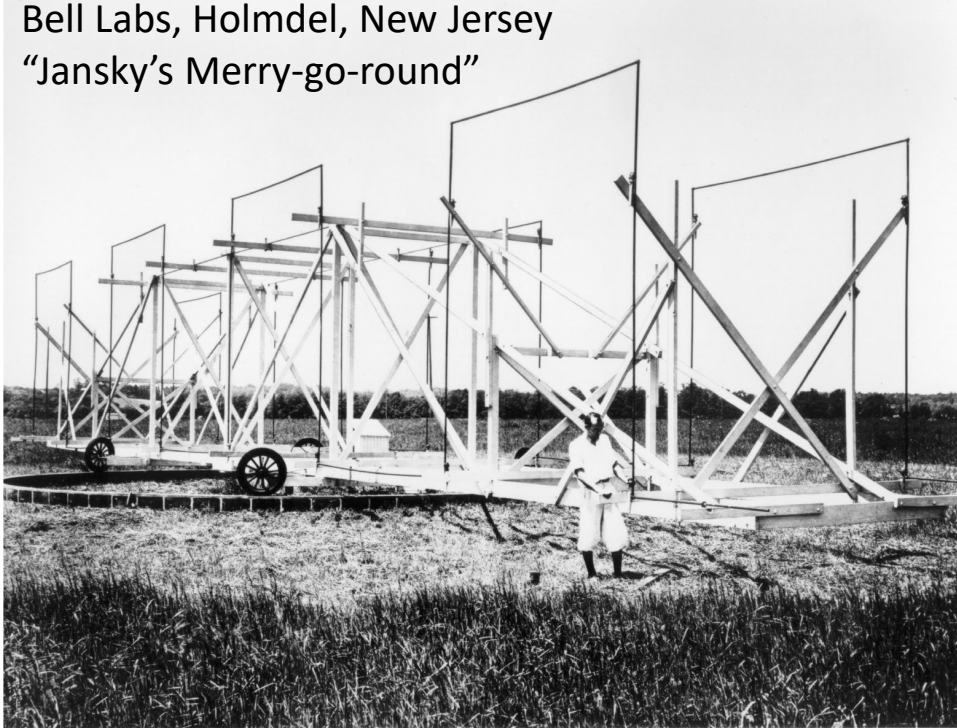
- Doppler effect: emitter and gas velocity can be evaluated
- “I often think of atomic hydrogen as smoke particles in a room. If you open the door in a smoky room, you see the draft in the smoke particles’ movement. The same thing is true with hydrogen gas in the galaxy” Naomi McClure-Griffiths

Karl Jansky – Discoverer of Radio Astronomy

Karl Guthe Jansky (October 22, 1905 – February 14, 1950)

acknowledgements: Justin Jonas; NRAO

Bell Labs, Holmdel, New Jersey
“Jansky’s Merry-go-round”

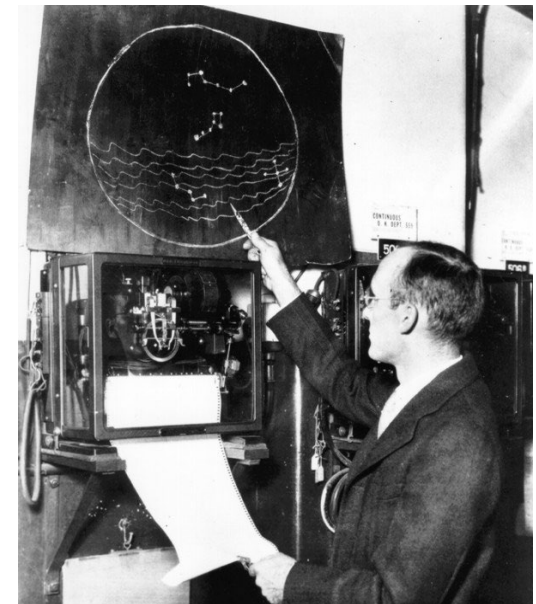


“Electromagnetic waves of an unknown origin were detected during a series of experiments on atmospherics at high frequencies.”

“... the waves come from some source outside the solar system.”

$$1 \text{ Jy} = 10^{-26} \text{ W.m}^{-2}.\text{Hz}^{-1}$$

- Bell Labs young engineer (not radio astronomer) trying to find sources of static in their overseas radio comms.
- Built rotating antenna for all-sky coverage. Detected thunderstorms and fluctuating strange hiss



RFI and Radio Astronomy: What's the Fuss

from RT Lord

- A simple calculation to **show how small 1 J is**:
- Point 26m HartRAO dish (assume 70% efficiency) for 30 years to one of brightest radio sources, **Virgo A**
- Each day, we would be able to receive radiation for a max of 12 hours (earth rotating)

$$\begin{aligned} E_t &= P_t \cdot t \\ &= [S \cdot A_e \cdot B] \cdot t \\ &= \left[201.81 \cdot 10^{-26} \cdot (13^2 \cdot \pi \cdot 0.7) \cdot 256 \cdot 10^6 \right] \cdot 30 \cdot 365 \cdot 12 \\ &= 25 \text{ nWh} \end{aligned}$$

By comparison, a 100 W lightbulb, switched on for 1 second, consumes 28 milli-Watt-hours of energy, i.e. more than a million times more than our 26 m dish receives from Virgo A in 30 years

Cellphone on Moon

further from RT Lord – RFI and Radio Astronomy: What’s the Fuss

- Transmit power: 0.5 W
- BW: 12 kHz (GSM standard provides channel spacing of 200 kHz, with each channel approx 12 kHz bandwidth.)
- Average distance from Earth to the Moon about 380 000 km

$$\begin{aligned} S_{\text{cellphone}} &= \frac{P_t}{4\pi R^2 B} \\ &= \frac{0.5}{4\pi (380 \cdot 10^6)^2 \cdot 12 \cdot 10^3} \\ &= 2.3 \cdot 10^{-23} \text{ [W/m}^2\text{/Hz]} \\ &= 2300 \text{ [Jy]} \end{aligned}$$

Some of the strongest radio sources at 1420 MHz include:

Our sun: 700 kJy

Virgo A: 201.81 Jy

Hercules A: 46.52 Jy

Hydra A: 42.37 Jy

Cellphone on will appear ten times brighter than **Virgo A**
a cluster of galaxies

Pulsar Origins and RFI

- 1933 Karl Jansky at Bell Labs
- Post WWII Ratcliffe started ionospheric research group at Cavendish
 - supervised Martin Ryle, Bernard Lovell and Antony Hewish
- Oct 1965 now Dame Jocelyn Bell Burnett PhD on better understanding quasars (energetic radio galaxies)
- 6 Aug 1967 after 1-2 years on construction of 4 ½ acre phased array. 120 miles of wire and cabling!
- 96 ft chart recording/day rolled out on Cavendish research attic floor
 - persistent study: ¼ " of record had "impulsive signal"
 - checked previous records; saw in same sky portion
 - sped up tape and saw 1.33 second period pulses
 - then observed on Robin Collins and supervisor Paul Scott array
 - "**LGM**" until 3 other pulsars elsewhere, first 21 Dec 1967
 - not constant frequency;
 - couldn't be directed comms from different sky sources

Pulsar Array and RFI

- Much less interference in 1967, but still:
 - Pirate Radio Stations
 - Home Office allocated East Anglia Police for 1 week
 - 4.5 Acre and part of Collins Array; 3-mile telescope

[History | Cavendish Astrophysics](#)



To the SKA Environment



Engineering Challenges – barren sites

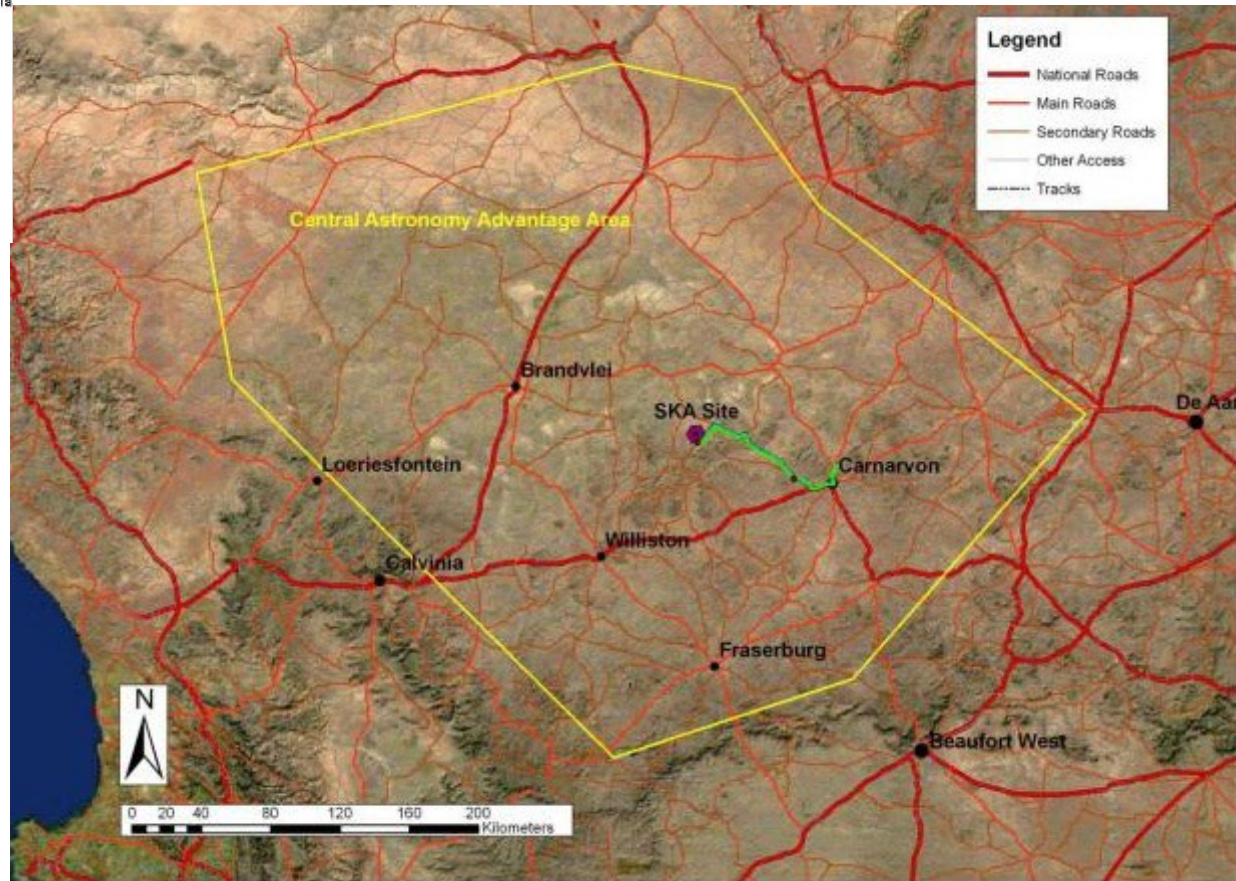
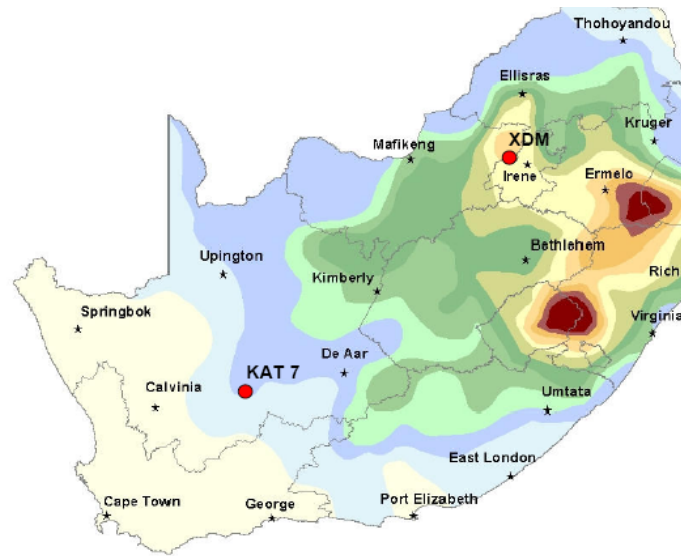


EMC Reality and Beginnings

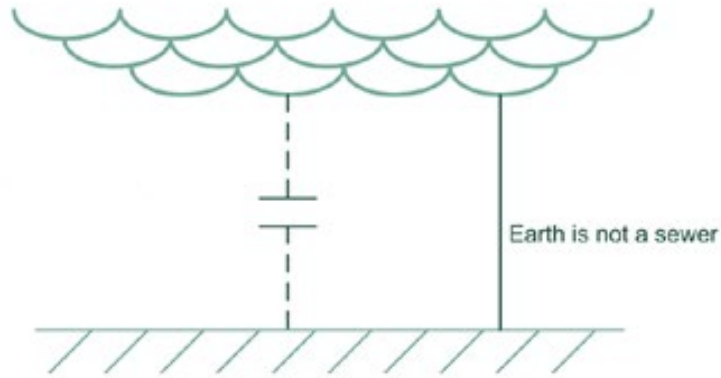


Scale and Context of SKA-Mid

- Immediate topics were linked to
 - Lightning flash density
 - Power line layout
 - Keeping “pristine” RF conditions



Perspective on Large-scale Projects



General Acknowledgements to:

Prof Piet CT van der Laan (Lex v Deursen)

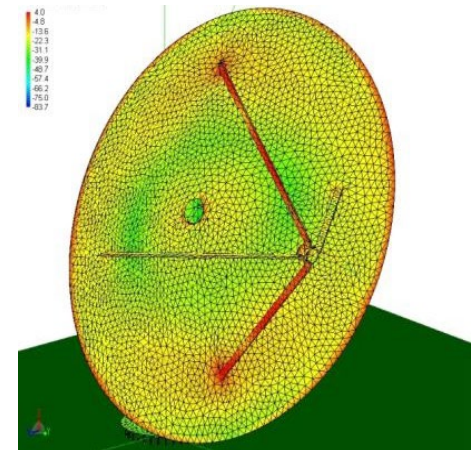
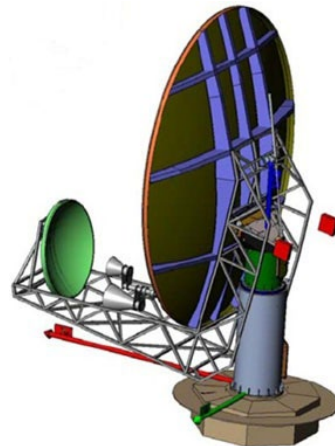
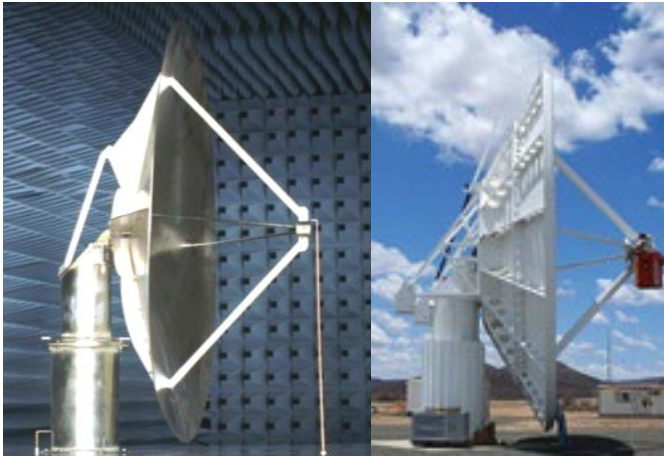
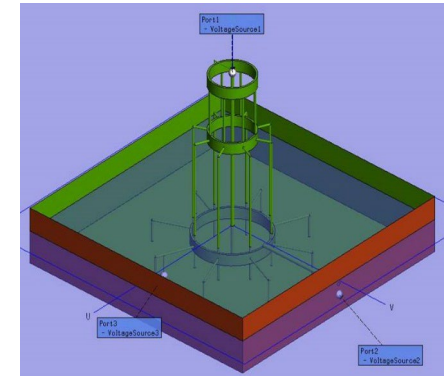
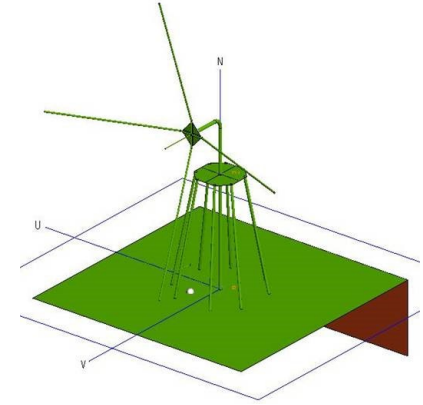
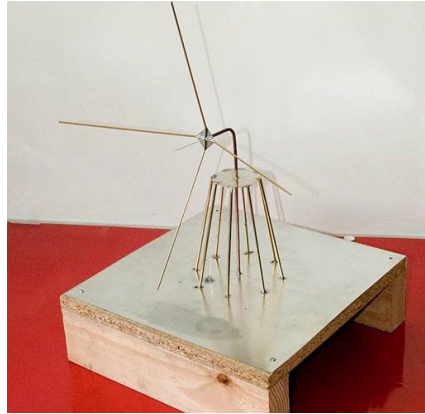
Dr Dave Giri

Colleagues & Postgrads at Stellenbosch University



Early System EMC Story in South Africa

Became clear that EM Model Verification and Confidence Evolution was going to be needed



NRF Bursary Programme:

“Pan-African” with international support

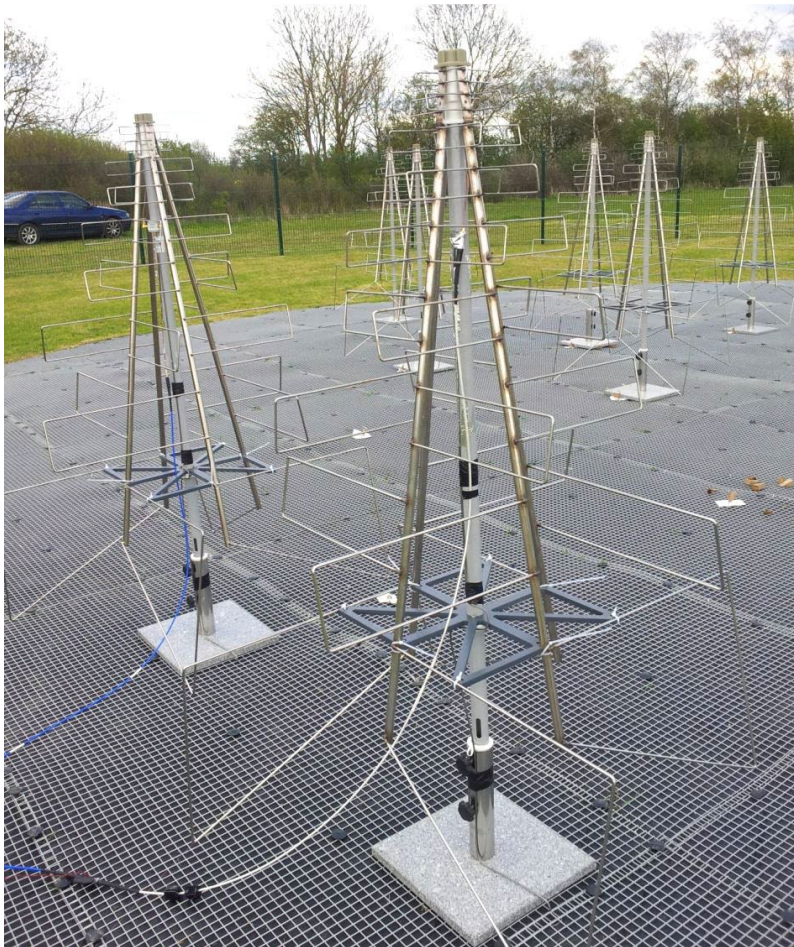


Early Investigations



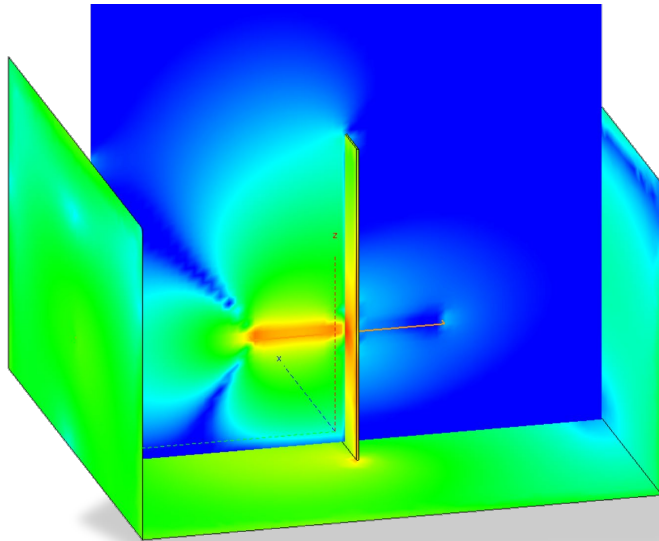
SKA Antennas at Lord's Bridge

- Pre-cursors at Stellenbosch and Paardefontein
 - (Dirk Baker: JD Kraus acknowledgement)
- Refined development including amplifiers, mechanical deployment, here



Postgrad Course – 12 weeks 20 hr/week

needed good foundation for students and RSA consulting designers



Collaborative campaigns including sparking on fences



System Planning from Start and Regular Checking

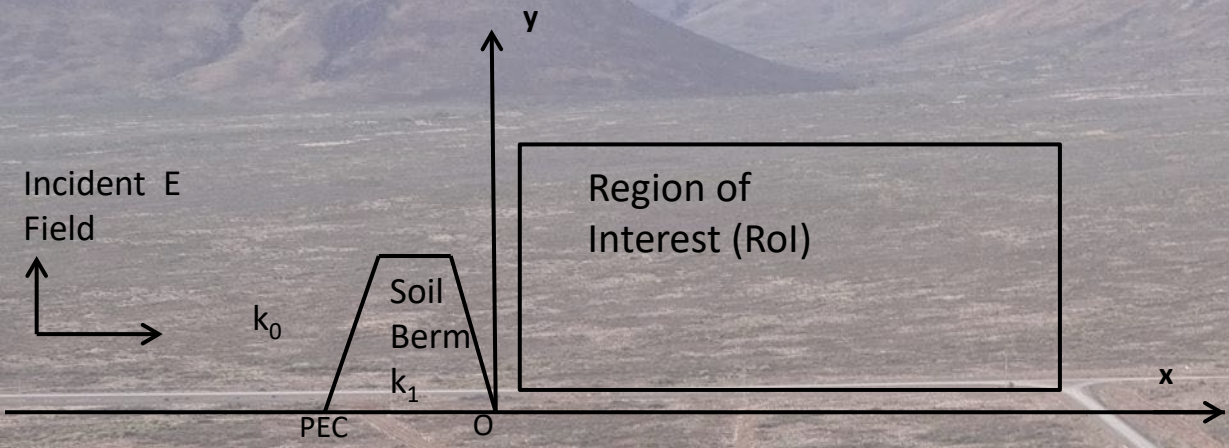
- The wider family



KAPB: Collaborative interactions eg power entry interface detail

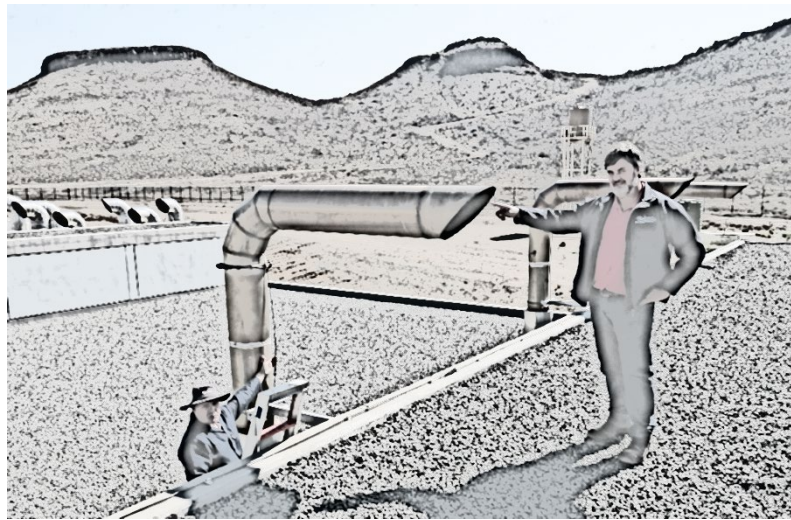


Site Base Infrastructure



Flight [link](#)

KAPB SE Deep Dive





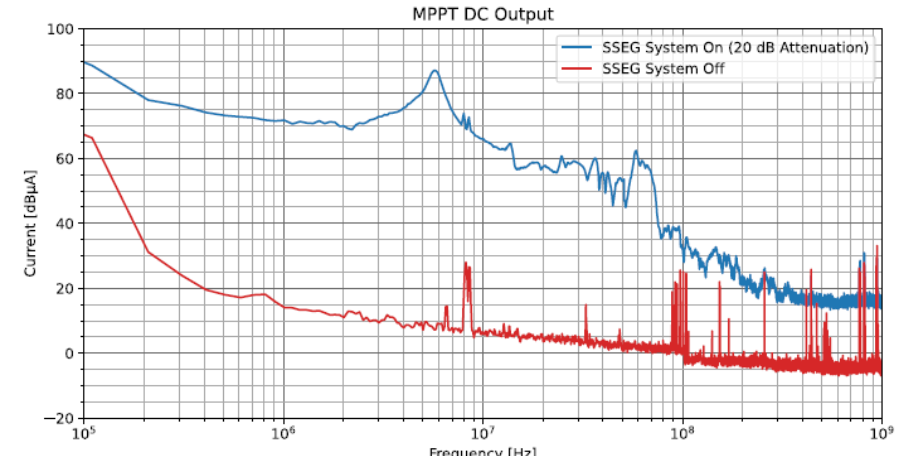
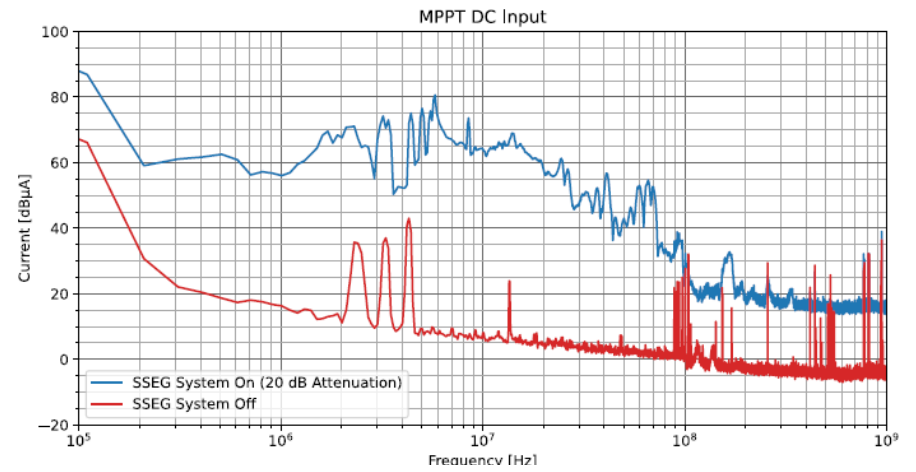
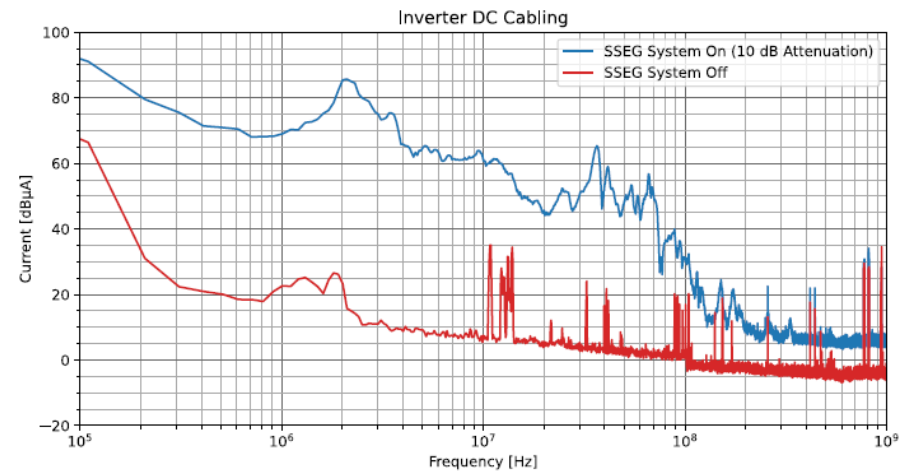
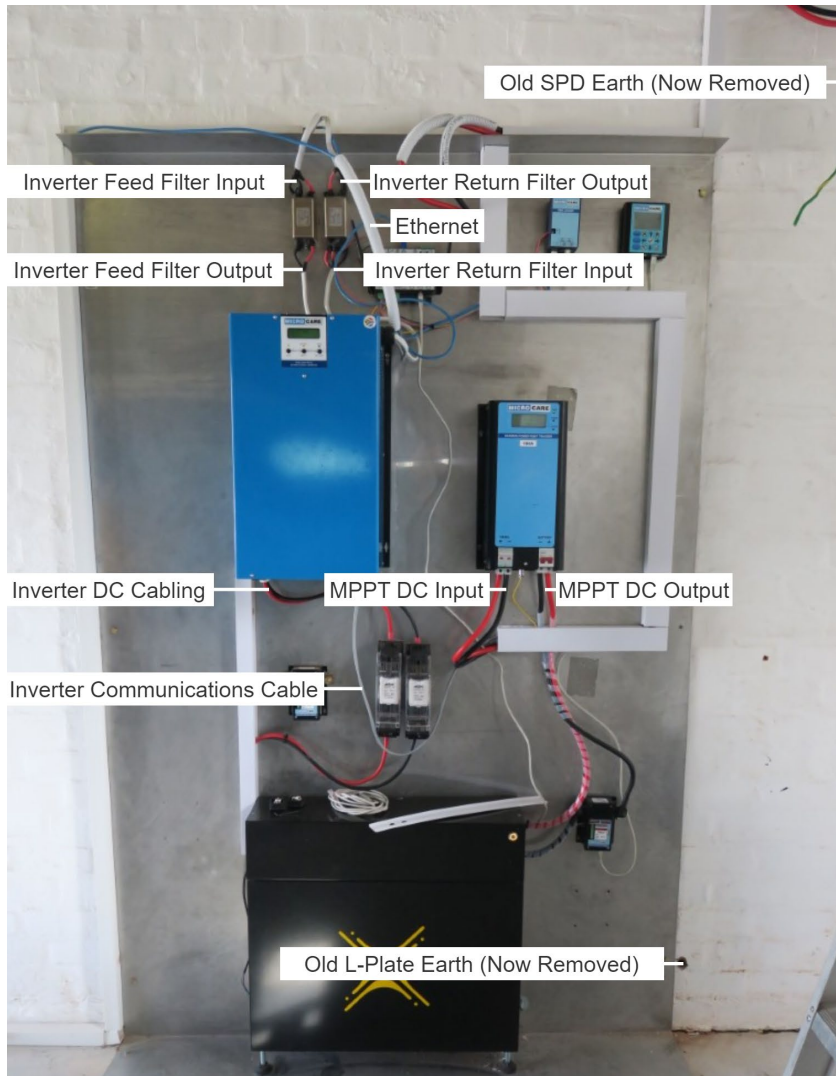
Visualising Cables in the Core

... and what current path / coupling mechanisms possible?

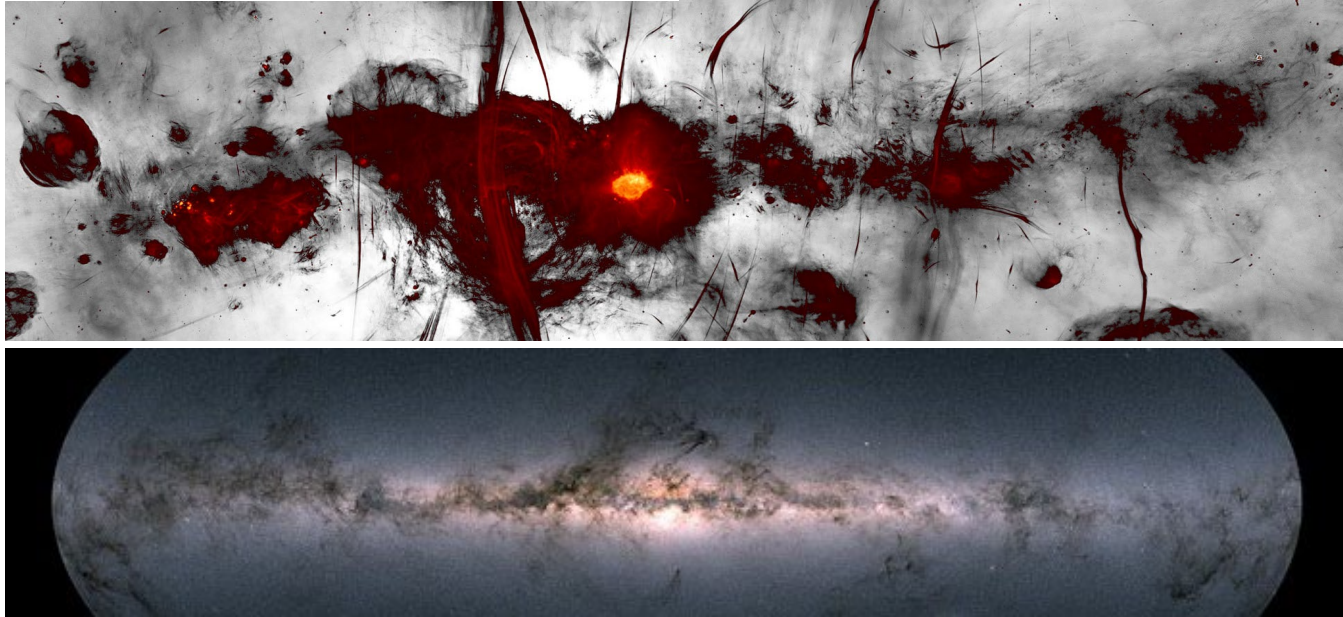


PV System RFI

pages of history torn from our diary



MeerKAT Milky Way Galactic Centre Image



Gaia shut down 27 Mar 2025

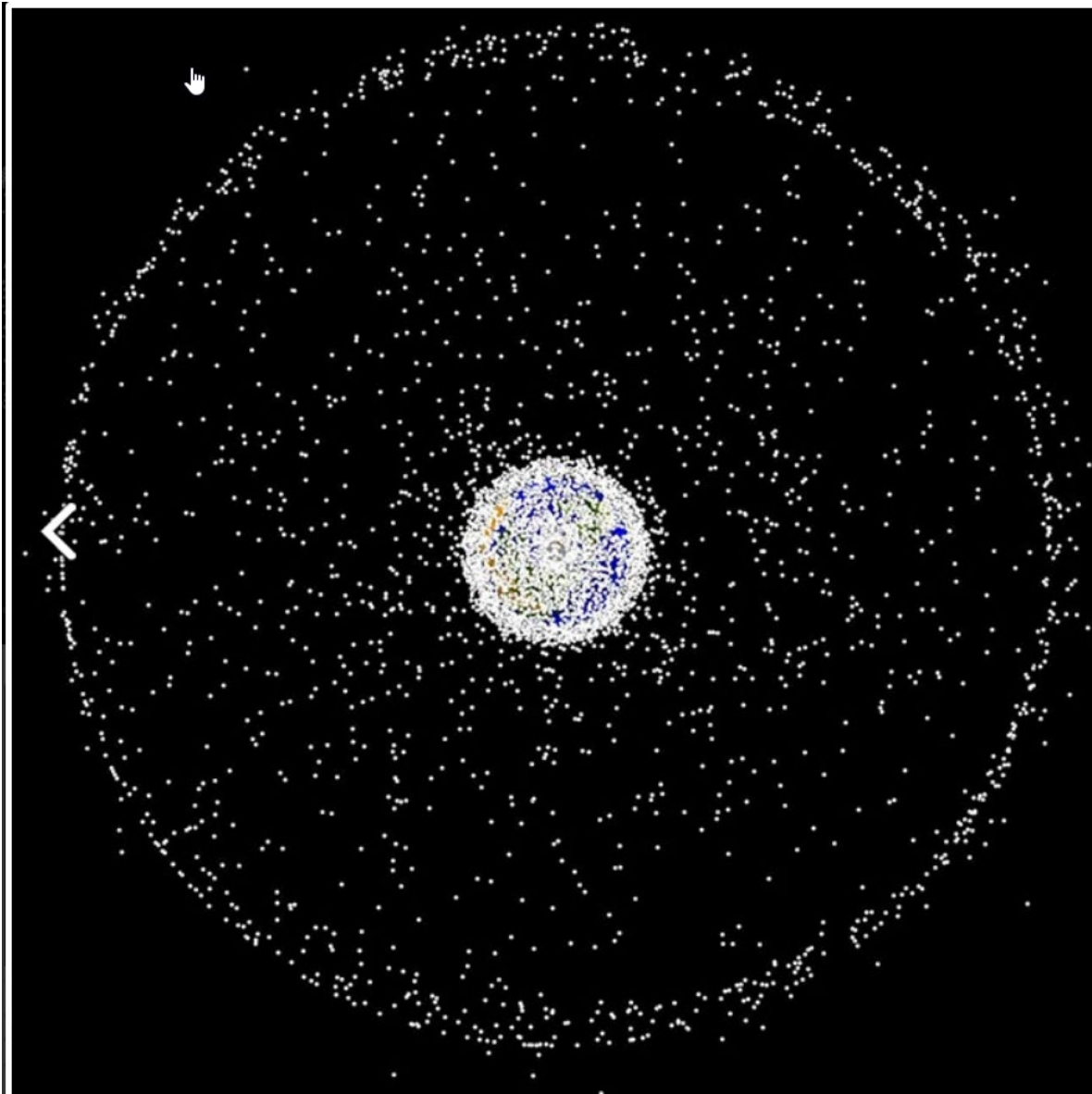
Dr Rainer Schödel: Head of the Galactic Centre Group, Institute of Astrophysics of Andalusia in Spain.

- Centre of our galaxy, 26,000 light years away, *supermassive* four million solar mass black hole, Sagittarius A*
- Optical telescope Gaia unable to peer into region because interstellar dust blocks light
- Can be observed at > 100 times higher resolution than nearest centre of a comparable galaxy, Andromeda; fundamental laboratory for astrophysics
- Inner ~500 light years around Sagittarius A* is galaxy's most active star-forming region
- By studying changes in pulsar clocks "tick", Einstein's general theory of relativity tested in the most extreme gravitational environment possible
- MeerKAT image also led to discovery of many supernova remnants

Side Notes

- The space between the stars is not empty; it contains interstellar dust and gas and gets enriched by stellar winds and supernova explosions. Dubbed the interstellar medium, it forms an interesting region to learn more about the process of star formation.
- “If we want to understand the Universe, we want to understand how galaxies go from being bodies of gas to being star-forming entities,” explains **Prof. Naomi McClure-Griffiths** (outgoing chair of the SKAO Science and Engineering Advisory Committee).
- “We need to study the evolution of the interstellar medium; how it goes from being warm and diffuse and just sort of hanging around, to being a dense, cold blob that’s self-gravitating and forms a star.”
- An important tracer for these studies is the 21 cm emission line from neutral hydrogen gas, which is abundant in the interstellar medium.

Tracked Space Satellites (95% Debris)

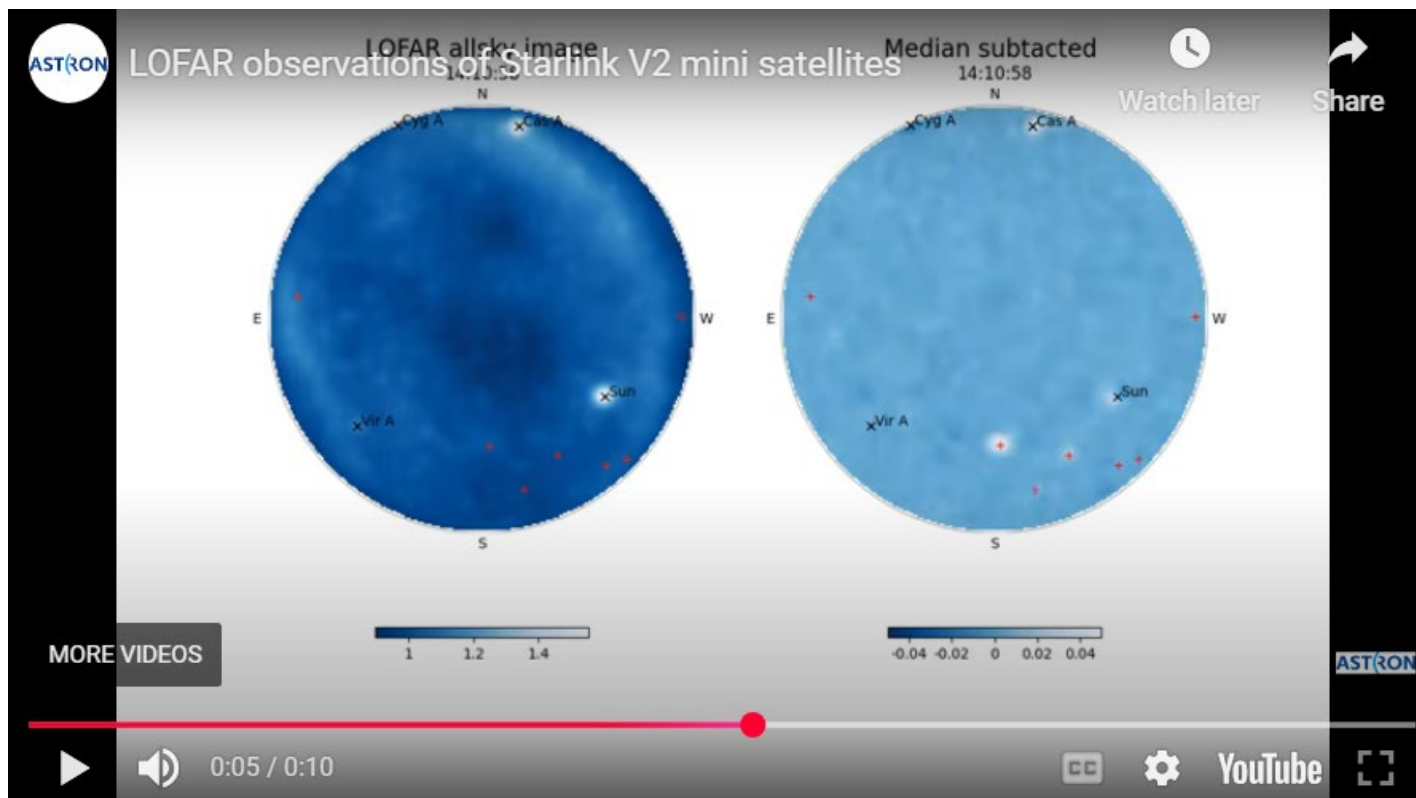


The GEO Polar images are generated from a vantage point above the north pole, showing the concentrations of objects in LEO and in the geosynchronous region. Credit: NASA ODPO.



Starlink

- ASTRON's LOFAR (Low Frequency Array) radio telescope show Starlink V1 satellites emit unintended radio waves
- 2024 show 'V2-mini' Starlink satellites unintended EMI up to 32 times brighter than V1, potentially blinding radio telescopes and closing RA windows of Universe
- Exact number of V2 Starlink satellites in orbit? Estimates suggest 6,400+
- Thus largest existing satellite constellation



Concluding Remarks

- Have we as EMC Engineers helped to look through our Milky Way in an attempt to unravel the mysteries of our Universe?
- More specifically, have we understood managing our own EMI?

tribute to international family

