Advanced technologies and developments in the radio domain

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ASTROPHYSICS FROM THE RADIO TO THE SUB-MILLIMETER
PLANCK AND OTHER EXPERIMENTS IN TEMPERATURE AND POLARIZATION
Bologna, 13-17 February 2012

To answer the open questions in modern Astrophysics: big projects

Radioastronomy plays a fundamental role in some subjects :

- HI line
- magnetism
- pulsars

Improvement in sensitivity, resolution, survey speed

New instruments and new technologies on the pathway to SKA-Square Kilometer Array

Precursors : ASKAP, MeerKAT

Pathfinders : APERTIF, EMBRACE, EVLA, LOFAR,
LWA, ATA, eVLBI, eMERLIN, ASKAMP

Design Studies : SKADS, BEST, PrepSKA, AAVP, TDP

→Many other projects all over the world

OUTLINE

Sardinia Radio Telescope

LOFAR

SKA Precursors : ASKAP , MeerKAT

SKA

Sardinia Radio Telescope SRT

Fully steerable, 64m diameter, paraboloidal radio telescope.

Alt- Azimuth mounting

Wide frequency range: from 300MHz to 110GHz.

3 main focal positions

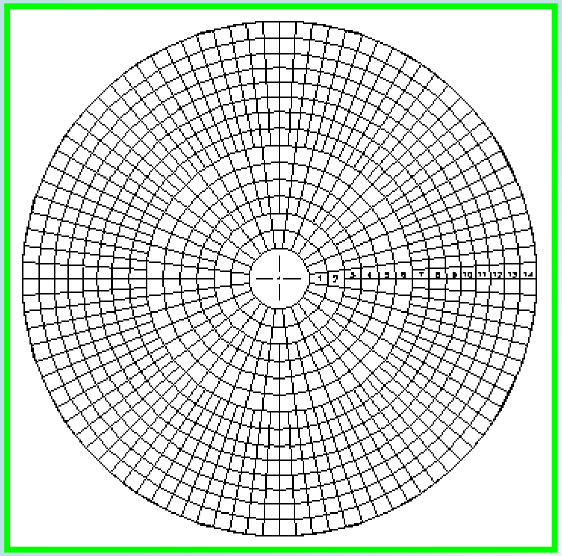
Can host up to 17 receivers

Active surface: efficiency ranges from about 63% (at ~10GHz)
to about 35% (at ~100GHz)

Fiber optic connection

Transmitting capabilities


S.Basilio (CA)



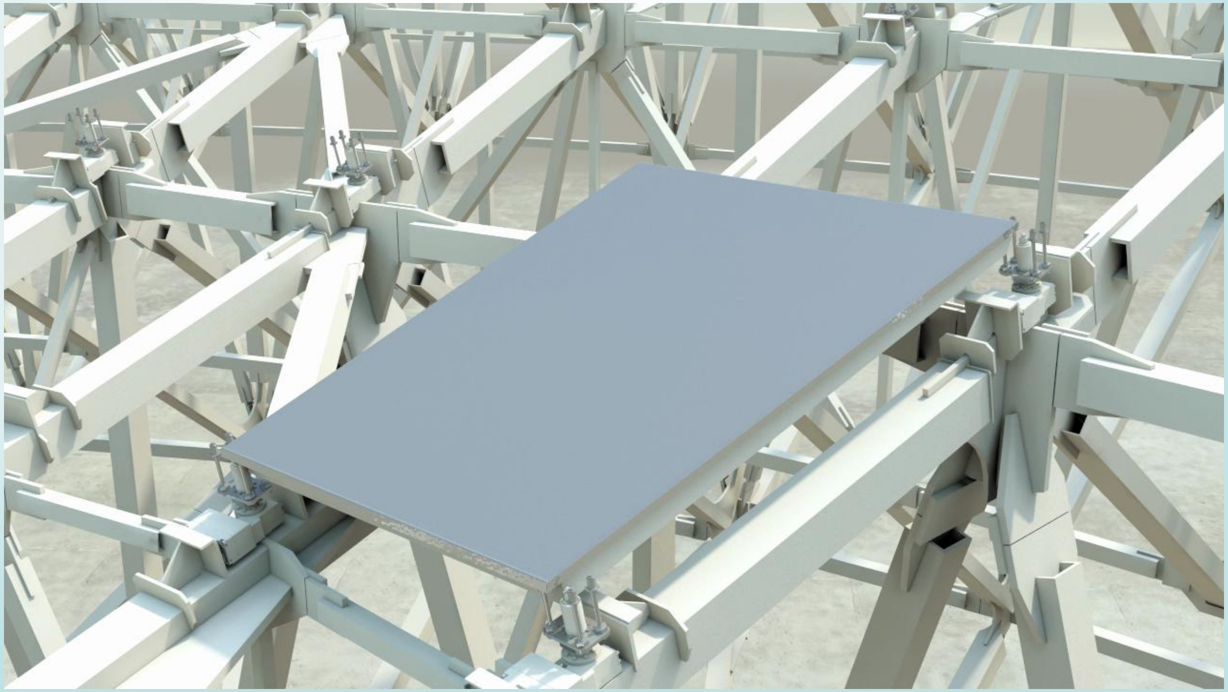
Main reflector active surface:

1008 panel + 1116 mechanical actuators

Alignment specs:

Panels : 500 µm (duty) → 300 µm (goal) rms

Panel 4-corners on each single actuator: ≤ ± 100 µm

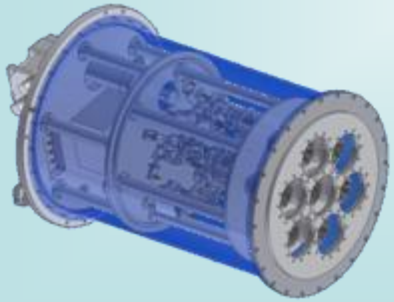


SRT First light RECEIVERS

310-420 MHz
1.3-1.8 GHz } Dual Band — Primary focus

5.7-7.7 GHz — Mono-feed — BWG focus

18-26 GHz — Multi-feed 7 pixels — Gregorian focus



L-R polarization (17 db)

LOFAR: Low Frequency Array

10-240 MHz

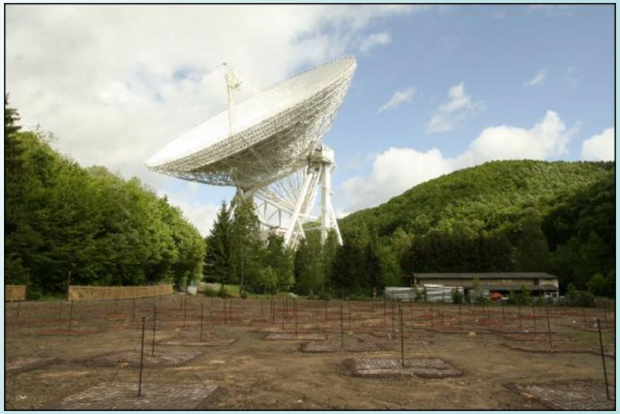
120-240 MHz 30-80 MHz

International LOFAR Stations

Chibolton, UK

Onsala, SW

Nancay, FR



Effelsberg, DE

LOFAR TECHNOLOGIES

- Omni-directional antennas
- Sensor distribution on a large size → high angular resolution
- High-speed data transport : Tbits/s
- High processing power : TFlops/s, use of supercomputers and novel computer architectures, GRID computing
- Ionosphere correction

ASKAP (Australia SKA Precuror)

36 dishes, each 12m diam, equipped with PAF

$30^{\circ 2}$ field of view FoV
simultaneous beams

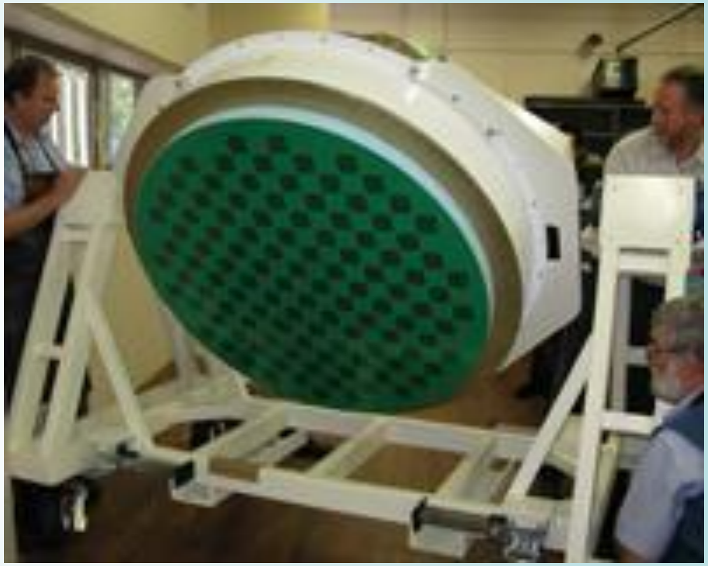
0.7-1.8 GHz, bandw 0.3 GHz, 16000 channels
➔ 20" res at 1.4 GHz,

max baseline ~ 6 km

ASKAP Technological Goals

- phased array feed (PAF) -- > wide field-of-view :
  30 separate /simultaneous beams of 1 sq deg
  to give a FoV of 30 square degrees at 1.8 GHz

- dual polarisation receivers



- Wide band operation with low RFI levels

- High polarisation purity

- Proof of infrastructure in remote desert environment (power supply, on site data transport)

- Cooling of the instrument's phased array feeds

Meer KAT (South Africa SKA Precuror)

64 dishes

13.5 m diam

Centrally condensed,
maximum baseline ~ 20 km

Meerkat

KAT 7 : 7 dishes
made of fibre glass
freq 1.2 – 1.95 GHz
max baseline 185 m

Meer KAT (cont.)

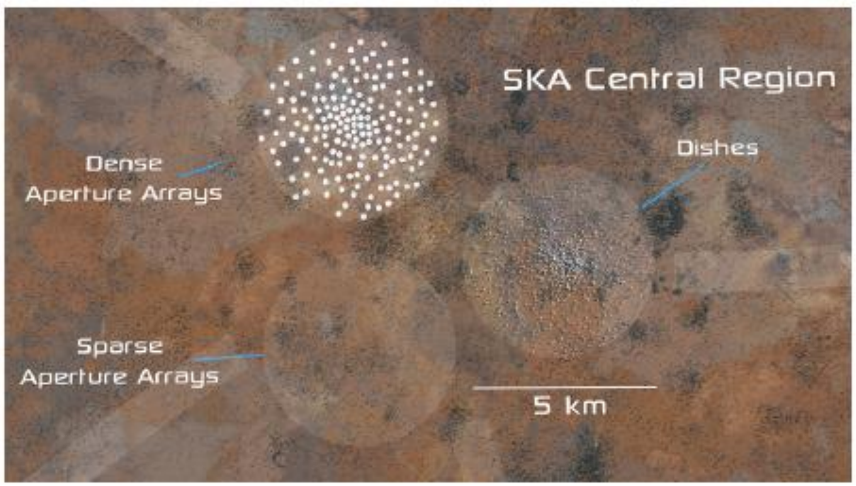
Three receivers cover the required operating band in the frequency ranges
0.58 - 1.015 GHz
1 - 1.75 GHz
8 - 14.5 GHz.

-offset Gregorian dish configuration → high aperture efficiency
low spill-over, low sidelobe level

compact core with 70% of the dishes + extended array

- high imaging dynamic range
- RFI rejection of radio frequency interference
- high fidelity imaging, resolutions from 6 arcsec to 100 arcsec.

SKA
SQUARE KILOMETRE ARRAY



SKA Specifications

Frequency : 70 MHz ÷ 25 GHz
Bandwidth : ± 50% of frequency
Spectral channels: 16384 per band per baseline

Rms Sensitivity : 400 μJy in 1 min at 70-300 MHz
200 μJy in 1 min at 0.3-10 GHz

Field of view: 200 deg^2 at 70 MHz
200-1 deg^2 at 0.07-1 GHz
1 deg^2 at 1-10 GHz

At least 4 simultaneous FoV

Maximum baseline : > 3000 km

Angular resolution : < 0.1"

Calibrated polarization purity: 10000:1

Image dynamic range : > 1.000.000

SKA facts

- 3000 antennas (feeds, receivers)

- 250 aperture arrays

- fiber optic connection
  signal trasportation (800 Tbit/s)

- computing capacity (exaflops: 10^{16}-10^{18} operat/s)
  new architectures/new algorithms

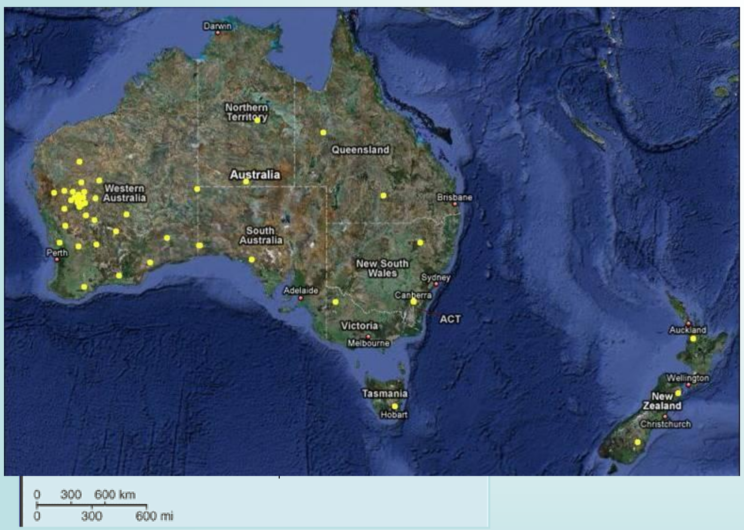
- data storage capacity (exa-byte)

- power requirements (up to 100 MW)

Sites for SKA

Extremely radio quiet environment
At least 3000 km in extent
Low ionospheric turbulence
Low tropospheric turbulence

Decision on site in 2012

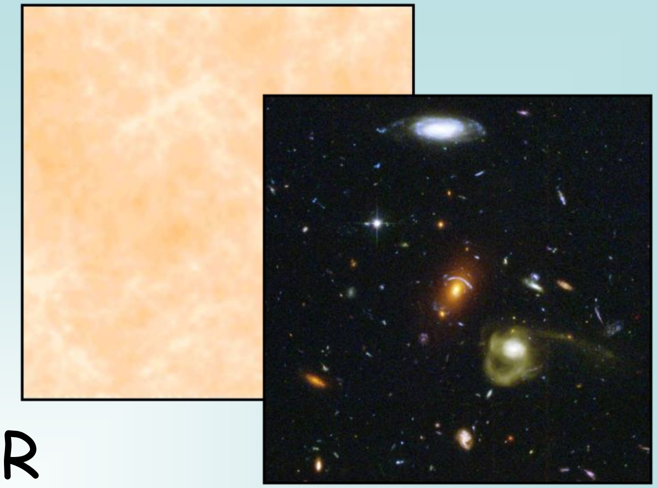


Australia + New Zealand
ASKAP

South Africa + 8 countries
MeerKAT

Science

SKA Key Science Projects



Origin of the Universe :

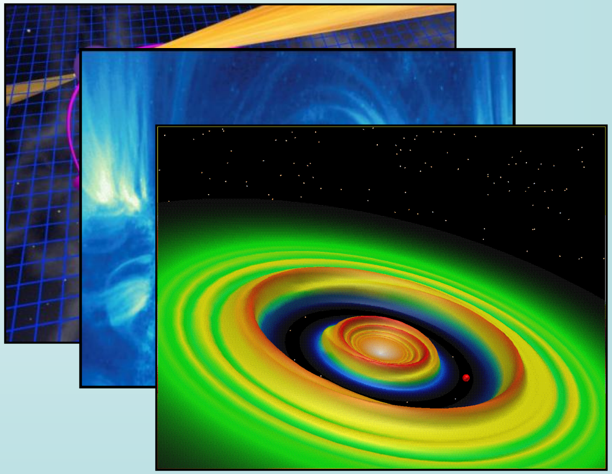
1. Formation of first objects/EoR
2. Evolution of galaxies/ Cosmology/ Dark energy

Fundamental Physics :

3. Pulsars/ General Relativity/ Gravitational Waves
4. Cosmic Magnetism

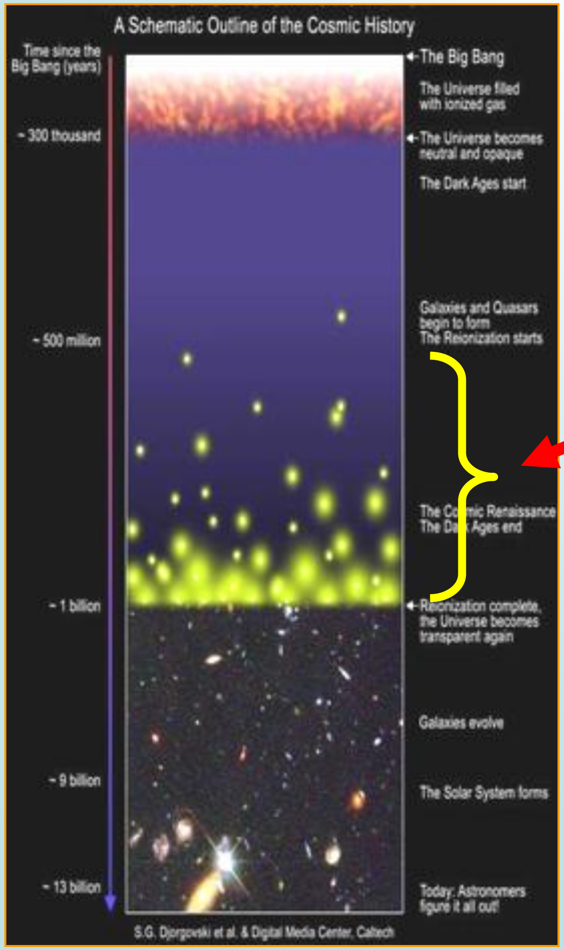
Origin of life :

5. Cradle of life and intelligent life



Epoch of Reionization

Carilli, Furlanetto, Briggs, Jarvis, Rawlings, Falcke, New Astronomy Reviews, 2004



<u>End of Dark Ages</u>

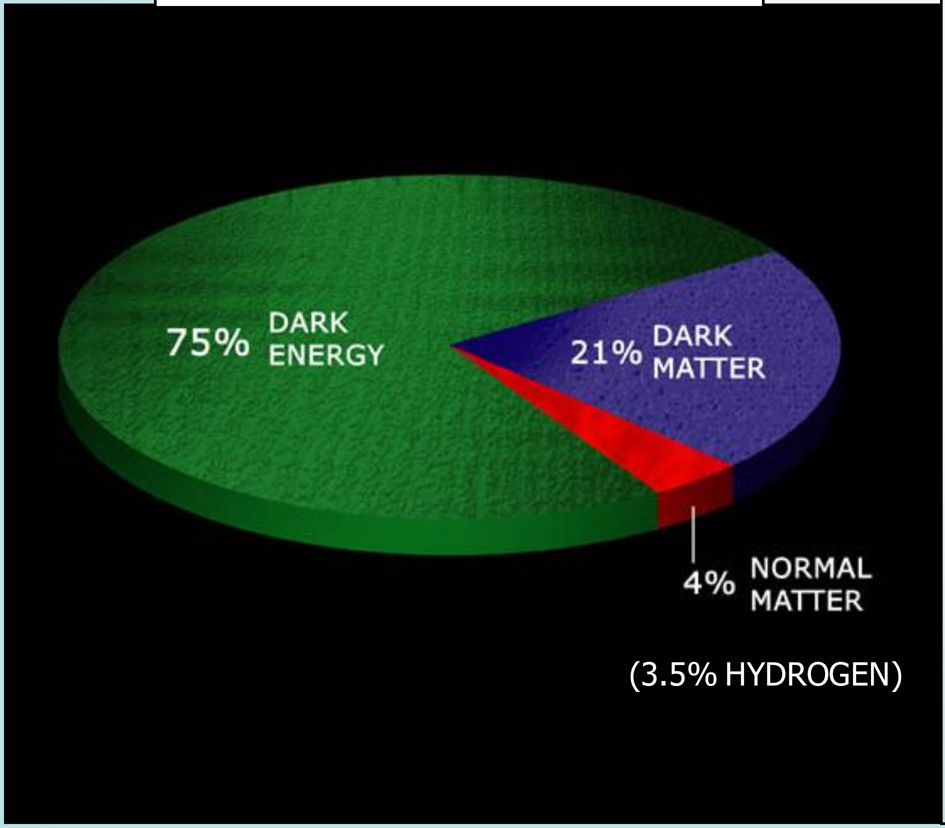
Era of the Universe
300 000 - 1 000 000 000 yr
after the Big Bang during
which the first stars and
galaxies formed

Detect and image hydrogen in the dark ages, provide 3D maps of the early cosmic web, shed light on the physics of the formation of the first objects in the Universe

Galaxies/cosmology/dark matter/dark energy

Rawlings, Abdalla, Bridle, Blake, Baugh, Greenhill, van der Hulst, New Astronomy Reviews, 2004

Composition of the Universe



Locate and measure spatial distribution of galaxies via their hydrogen emission

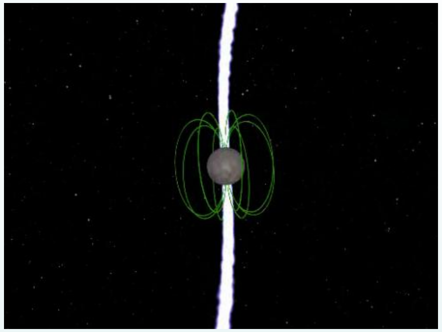
Derive information on Dark energy from the scale lenght of the distribution

10^9 galaxies in 3D space to z ~ 1.5

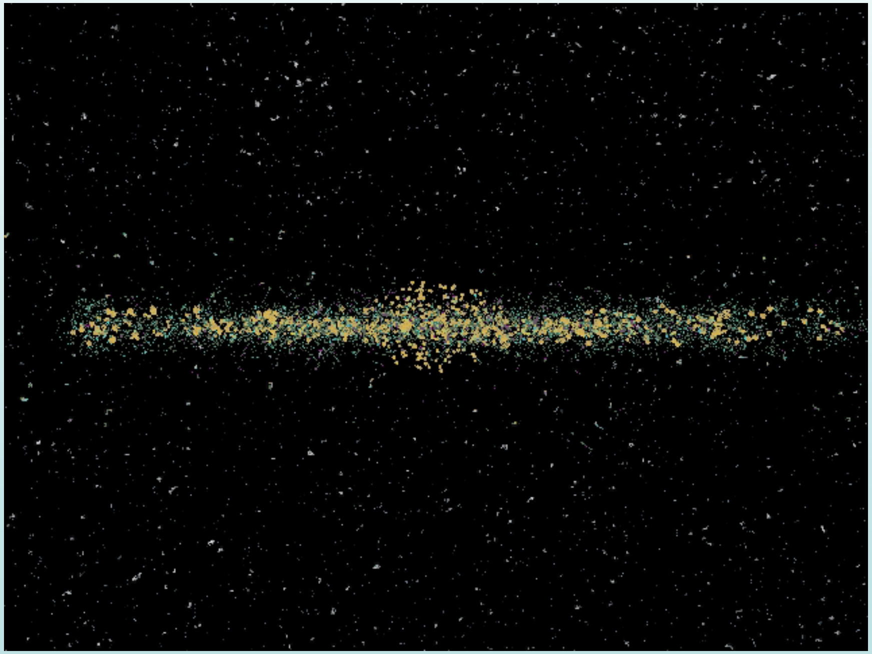
Planck, Euclid

Fundamental Physics: How Gravity works

Kramer, Backer, Cordes, Lazio, Stappers, Johnston,
New Astronomy Reviews, 2004



Pulsars have extreme physical properties:
highest gravitational fields: 200000 x solar
most accurate known clocks : 10^{-9} s



Physics may be different in strong GR
Gravitational waves

<u>SKA role:</u>
Blind survey will find 20 000 pulsars
in our Galaxy, 1000 millisec pulsars

many in binary systems and
exotic systems

-- LIGO
-- LISA

The Origin of Cosmic Magnetism

Gaensler, Beck, Feretti, New Astronomy Reviews,2004

Fundamental & unsolved problem:

- Exotic origin (phas transitions, strings)
- Seed fields (turbulence, instabilities)
- Amplification

Very powerful in the detection of total intensity and polarized emission and in RM measurements

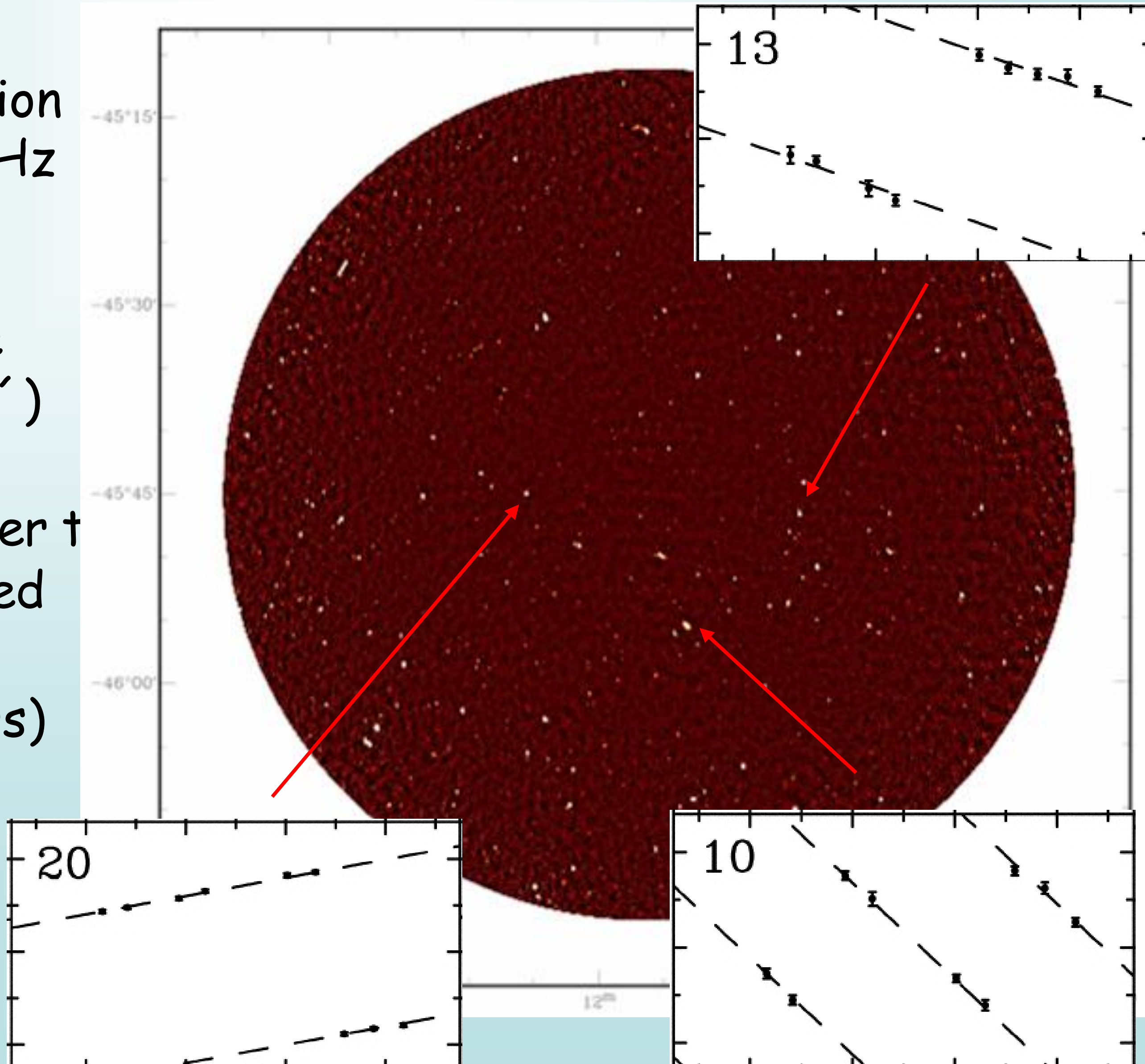
First detailed 3D picture of cosmic magnetic field:

- Polarization studies of 10 000 000 sources

SKA Faraday Rotation Survey

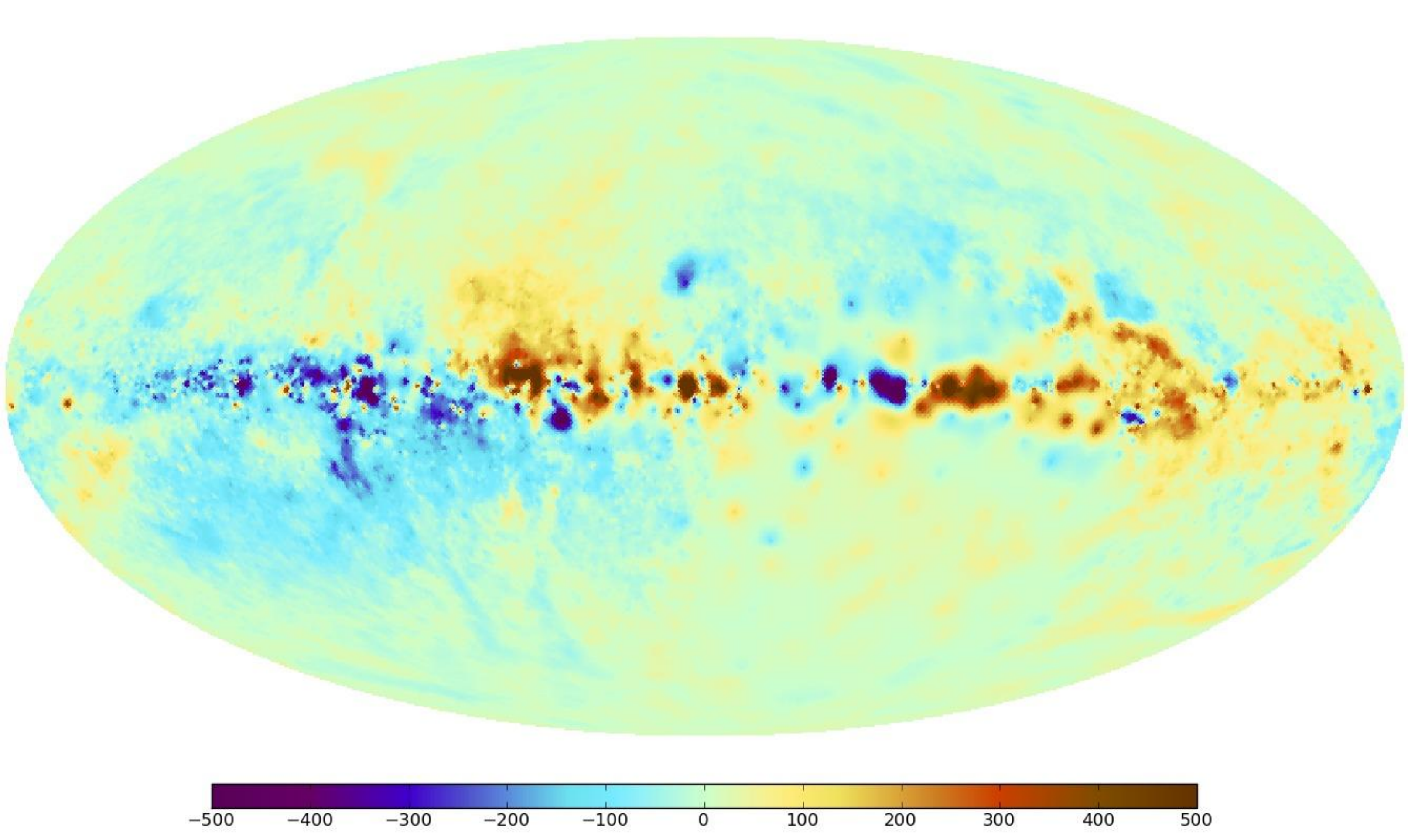
- Five min observation with SKA at 1.4 GHz
- Approx 500 RMs per deg^2 (average separation ~2´-3´)

➔ ~ 10^7 sources over t entire sky, spaced by ~90"
(~ 20000 pulsars)



Adapted from Gaensler et al. (2001) & Hopkins et al. (2003)

Also simulations by Krause et al 2009



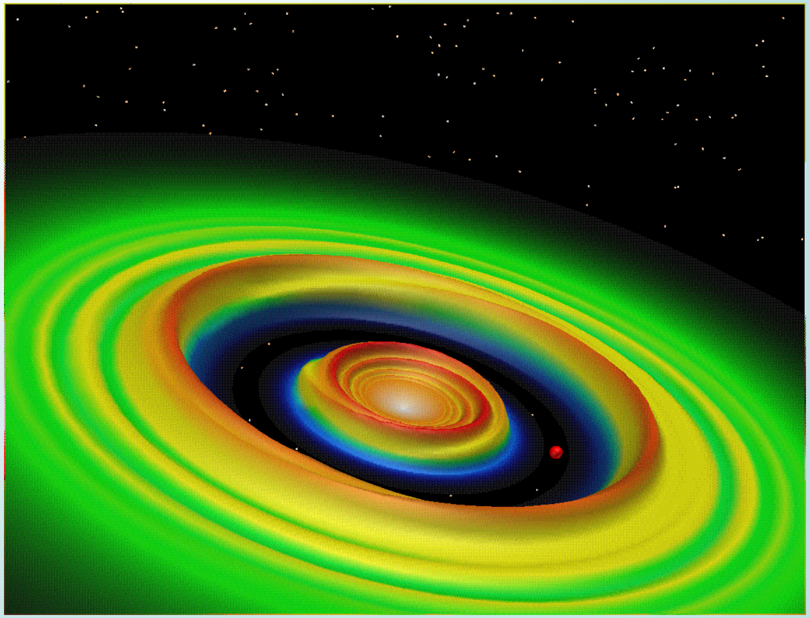
Faraday effect caused by the magnetic field of the Milky Way (Opperman et al. 2011)

The Cradle of Life

Lazio, Tarter, Wilner, New Astronomy Reviews, 2004

Test conditions for life elsewhere in the Universe

- Image proto-planetary disks in formation, movies, composition
- Probe the 'Habitable zone' in disks (mas resolution)
- Detect complex molecules



- Search for Extraterrestial Intelligence:

  Airport radars @ 50 l.y. → 500 stars

eMERLIN : galaxy evolution, AGN (eMERGE)
eVLBI : masers, SN

LOFAR : EoR, magnetism, survey

ASKAP : galaxy and BH evolution, LSS,
stars and stellar systems, magnetism

MeerKAT : Pulsar Timing, HI survey,
SFG and AGN

Total intensity survey : down to sub-μJy flux level

The MicroJy and NanoJy Radio Sky: Source Population and Multi-wavelength Properties

2011

Paolo Padovani*
European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching bei München, Germany

All objects that will be detected from currently planned all-sky surveys in X-rays, optical, infrared, will have **a radio counterpart** with SKA.

On large areas of the sky, and at lowest flux levels (< 0.1 µJy), radio sources detected with SKA will have no counterparts: rely only on radio information for size, morphology redshift, etc.

Optical match : only on small areas

ASKAP Survey Science Projects :

Evolutionary Map of the Universe (EMU)
Widefield ASKAP L-Band Legacy All-Sky Blind Survey (WALLABY)
The First Large Absorption Survey in HI (FLASH)
An ASKAP Survey for Variables and Slow Transients (VAST)
The Galactic ASKAP Spectral Line Survey (GASKAP)
Polarization Sky Survey of the Universe's Magnetism (POSSUM)
The Commensal Real-time ASKAP Fast Transients survey (CRAFT)
Deep Investigations of Neutral Gas Origins (DINGO)
The High Resolution Components of ASKAP: Meeting the Long Baseline Specifications for the SKA (VLBI)
Compact Objects with ASKAP: Surveys and Timing (COAST).

MeerKAT Survey Science Projects :

Looking at the Distant Universe with MeerKAT Array (LADUMA)

MeerKAT Search for Molecules in the Epoch of Reionisation (MESMER)

MeerKAT HI observations of Nearby Galactic Objects: Observing Southern Emitters (MHONGOOSE)

Transients and Pulsars with MeerKAT (TRAPUM)

MeerKAT International Giga-Hertz Tiered Extragalactic Exploration (MIGHTEE)

The Hunt for dynamic and explosive radio transients with MeerKAT (ThunderKAT)

A MeerKAT High Frequency Galactic Plane Survey (MeerGAL)

Conclusions

New intruments in the radio domain

Technological challenge :

- sensitivity
- field of view -> survey speed
- resolution
- high speed data transport
- high processing power
- high data storage capacity

Science : surveys

Thank you