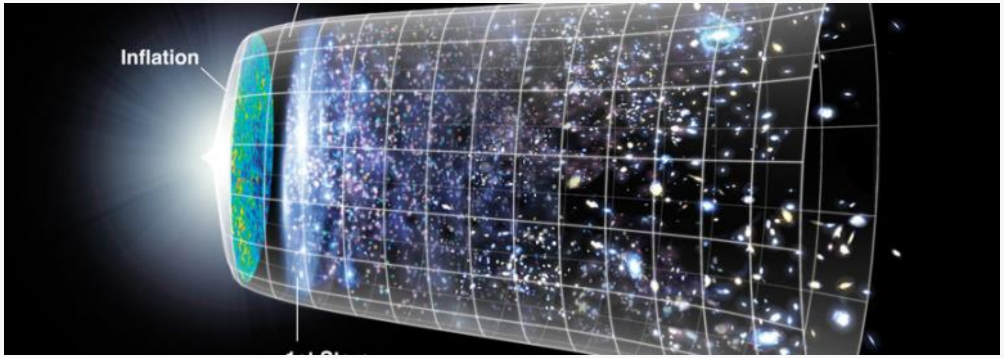
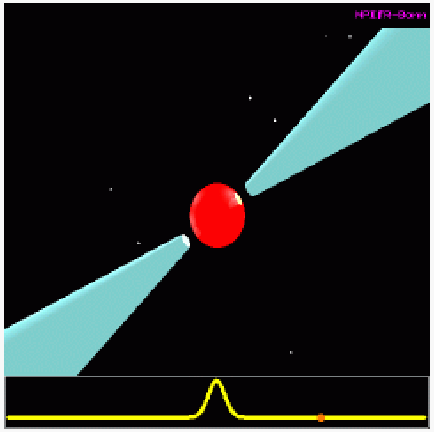




Science with the

Square Kilometer Array

SQUARE KILOMETRE ARRAY

L. Feretti, IRA-INAF,

Vulcano Workshop, 22-28 May 2016

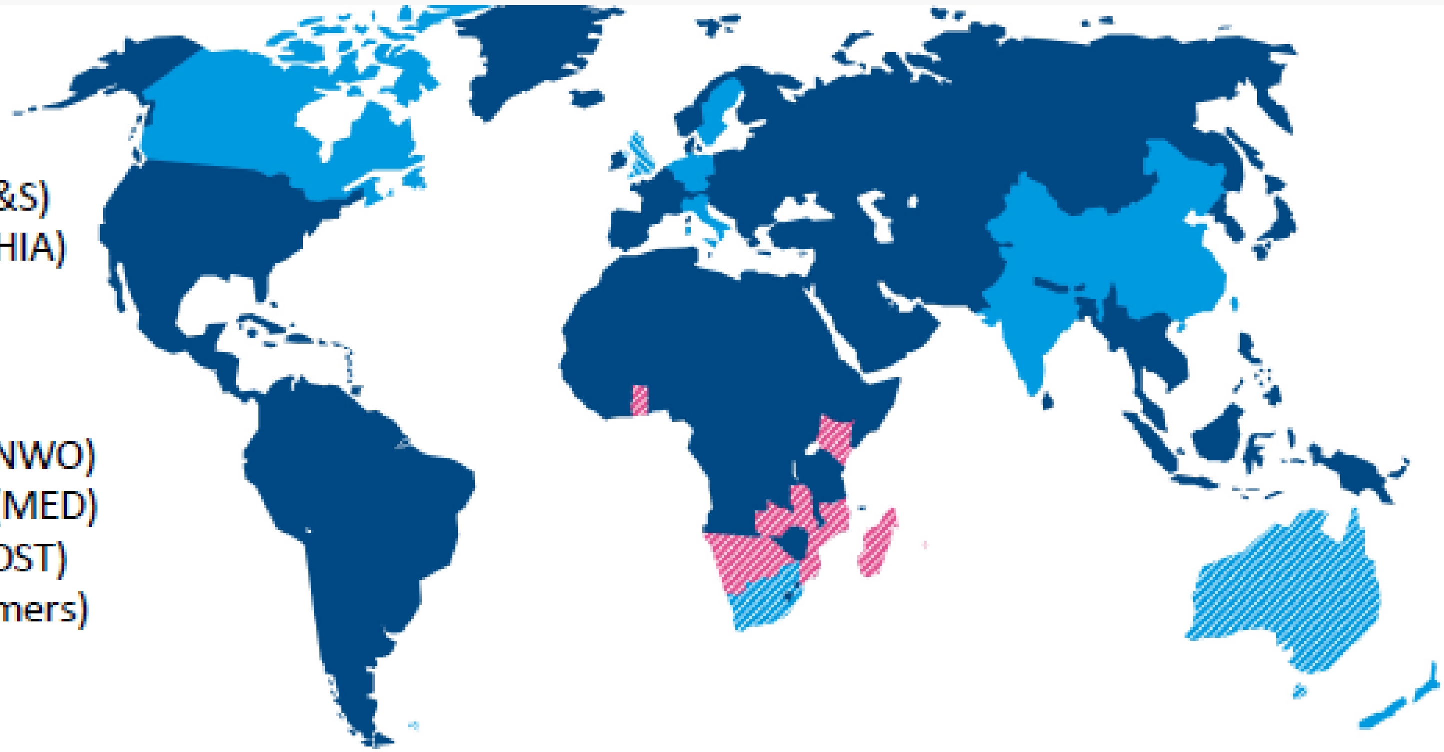
SKA: will be one of the great physics machines of 21st Century and, when complete, one of the world's engineering marvels (Robert Braun)

It will answer scientific questions of modern physics and astrophysics, through radio domain

- Fundamental physics: Gravity in extreme conditions, Dark Energy, Cosmic Magnetism
- Astrophysics: Cosmic Dawn, First galaxies, galaxy assembly and evolution; proto-planetary discs, biomolecules, origin of life, SETI
- The unknown: transients + ????

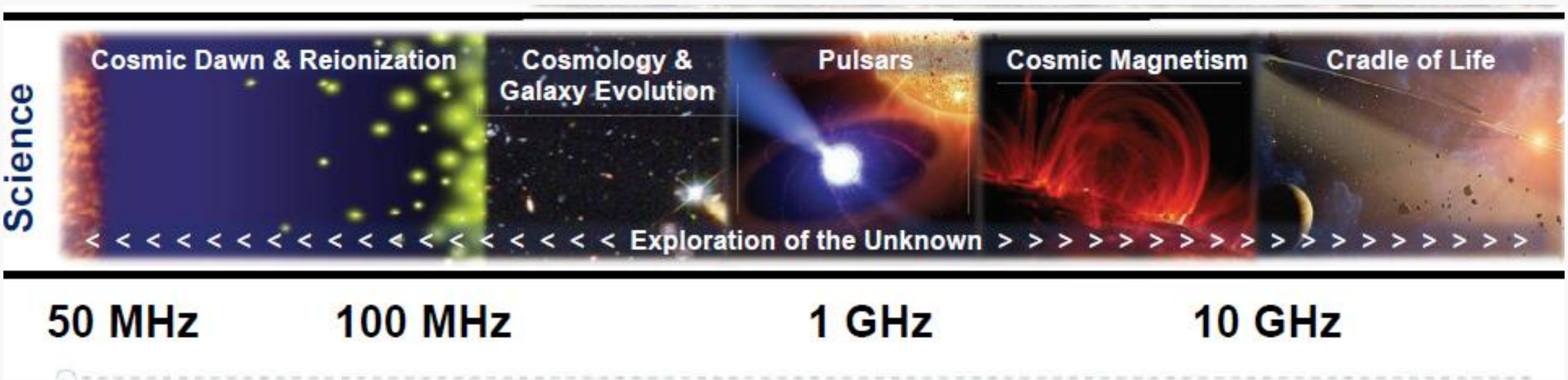
10 countries: more to join

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



Largest and most sensitive radio telescope (cm)

Up to 1 million m^2 collecting area distributed over a distance of ~3000 km on large frequency range (70 MHz – 10+ GHz)

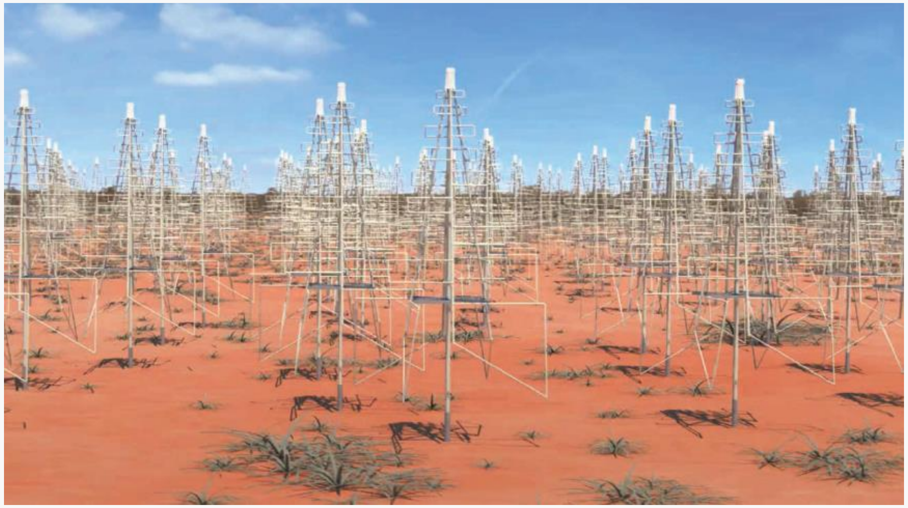


(courtesy R. Braun)

HI @ z = 10 : ν = 130 MHz

z = 20 : ν = 68 MHz

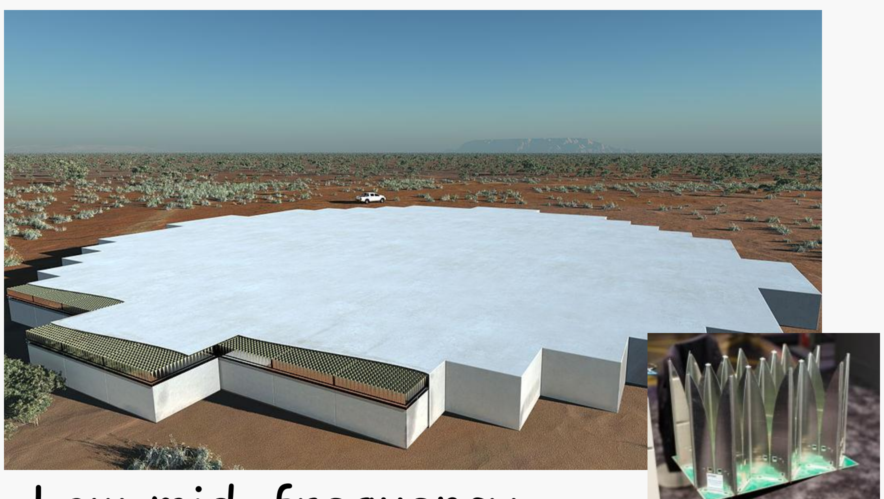
Different sensors



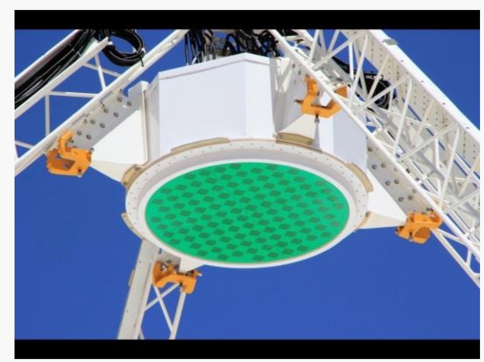
Low frequency (Aperture Array)

Mid frequency (Dish)

3 dish protypes in testing



Low-mid frequency



Phased Array Feed (PAF)

Elements are connected to a signal processor and to a high performance computing system by optical fiber ~ 80 000 km

Big data collection and storage:

data rates ~ 10 - 500 Tb/s

n of operations ~ 200 Pflops – 2 Eflops

processed data ~ 0.2 – 10 Pby/day

~ 100 Pby – 3 Eby per year of image data

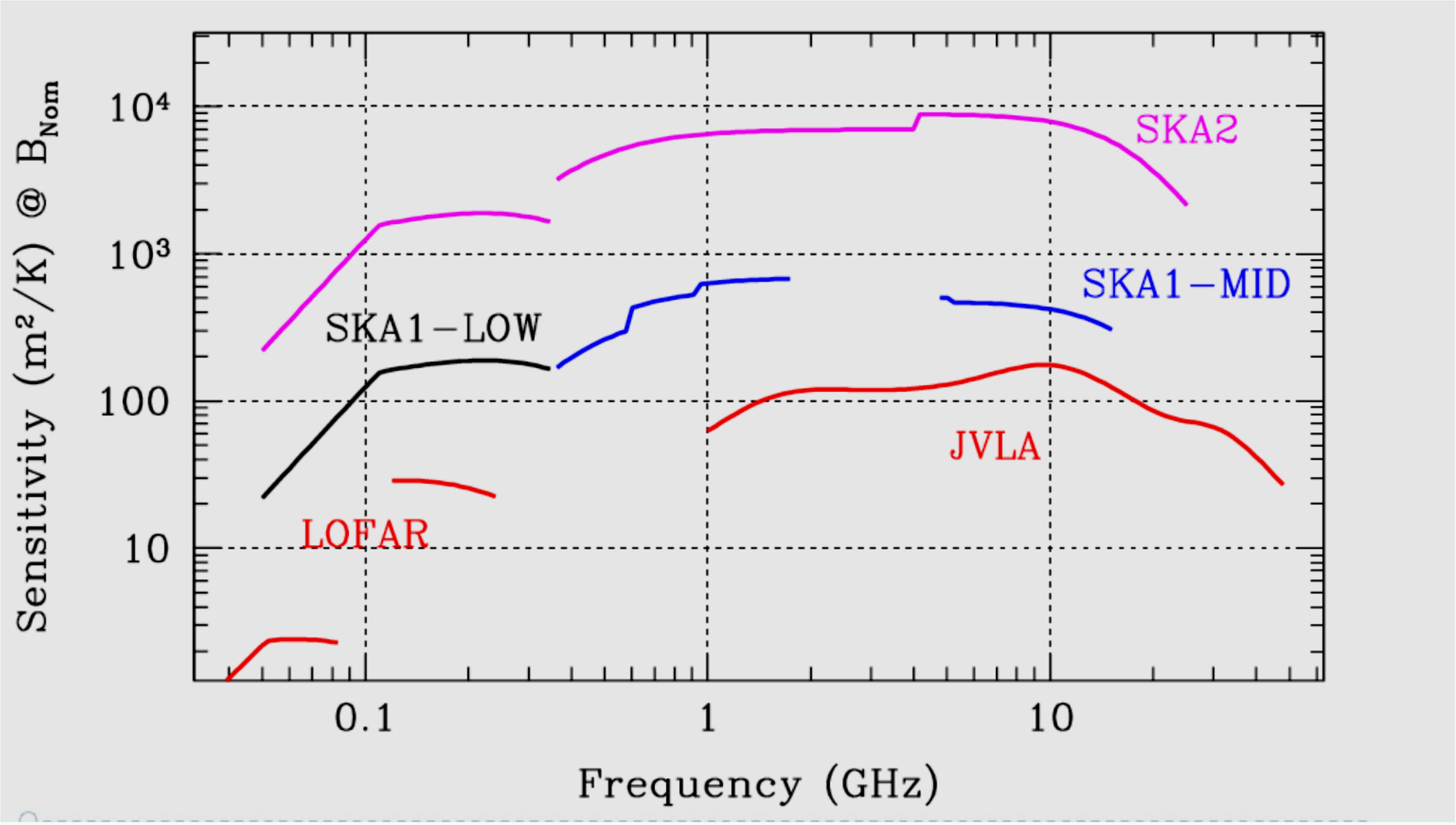
Realized in 2 phases

SKA 1

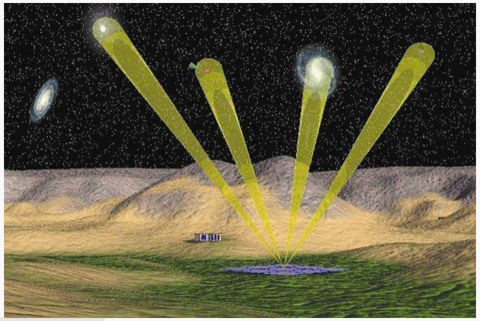
SKA 2

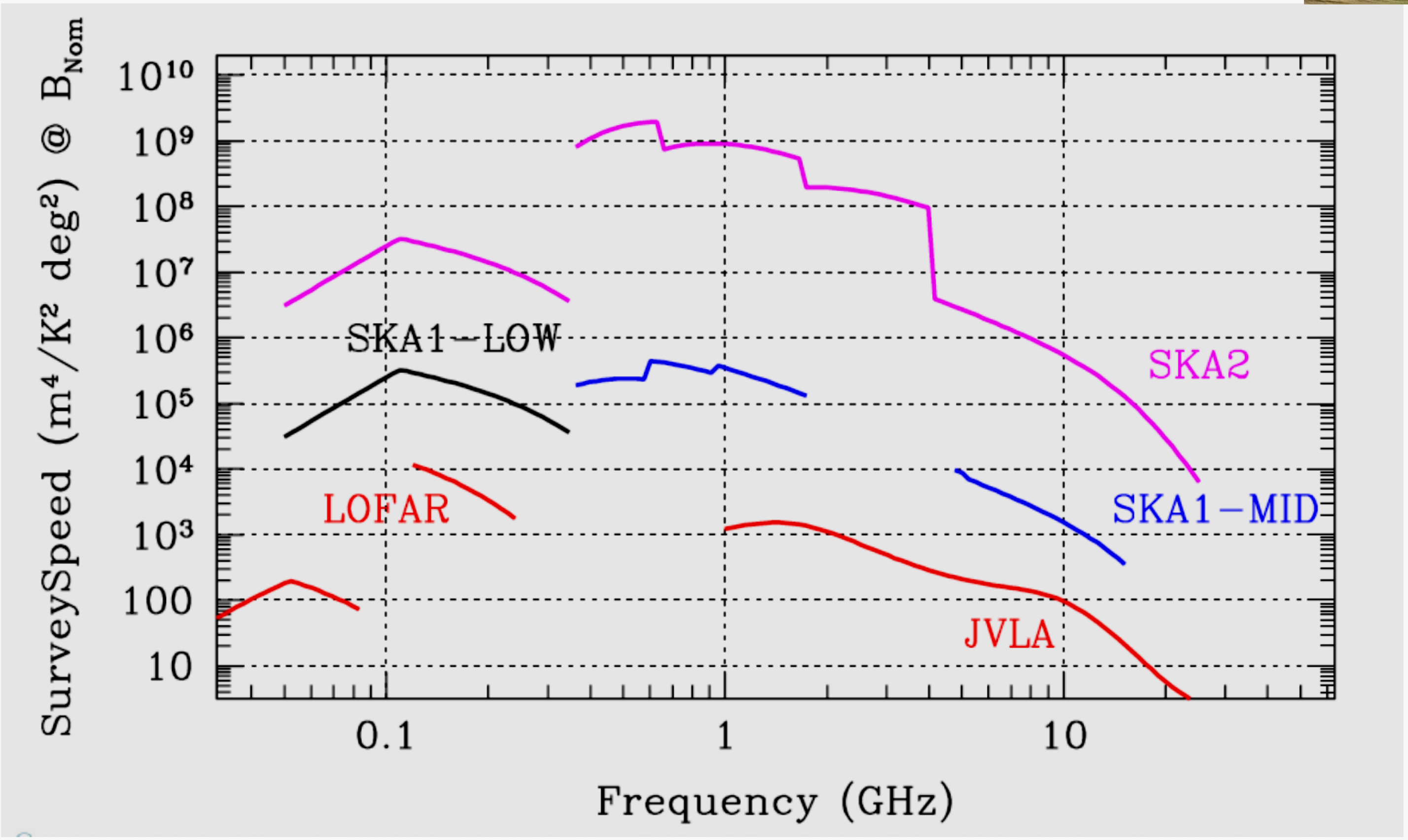
Courtesy R. Braun

Sensitivity



Survey Speed



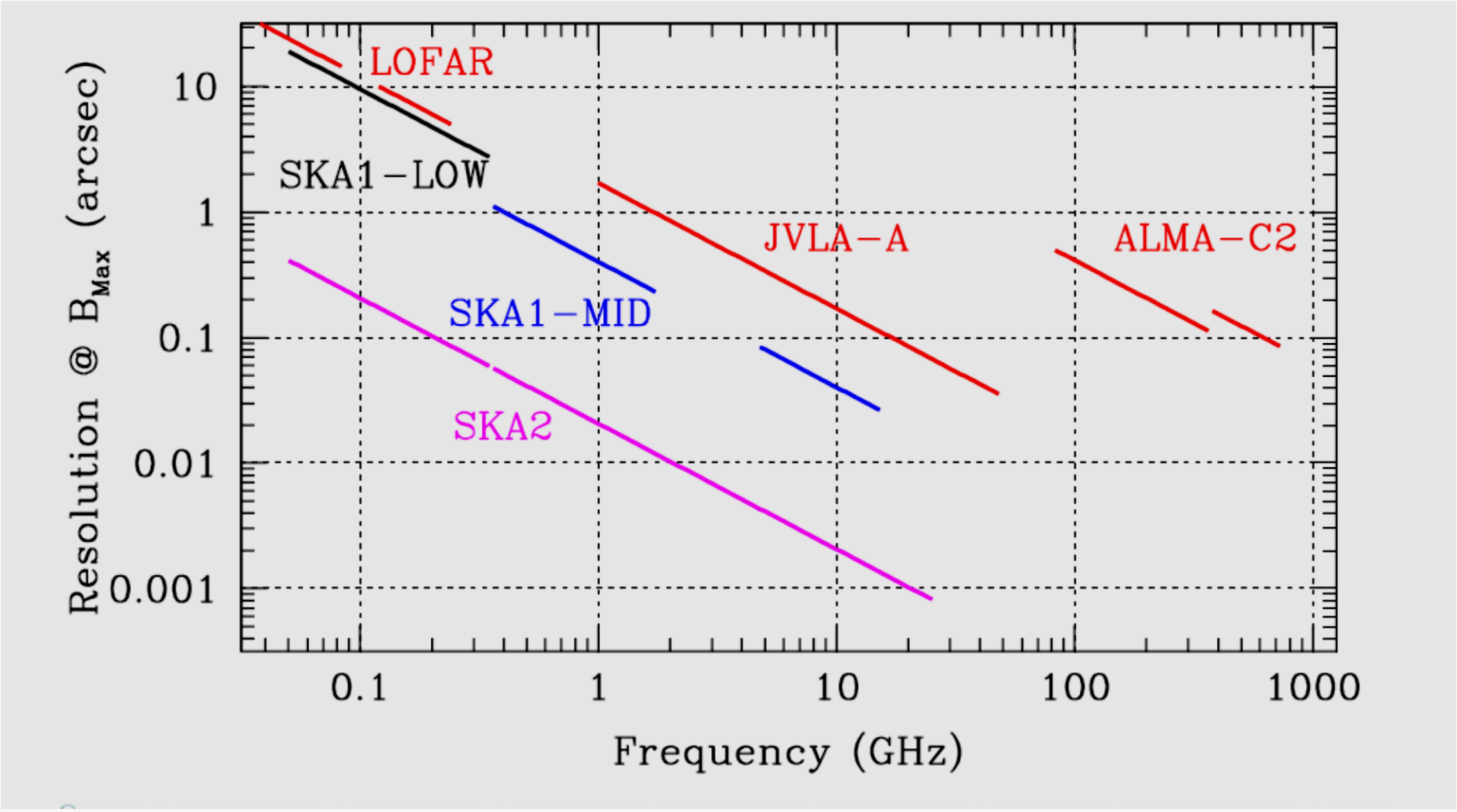


High Sensitivity + Large Survey Speed:

3 days to do survey like NVSS

(~ 10 months VLA over 3 years)

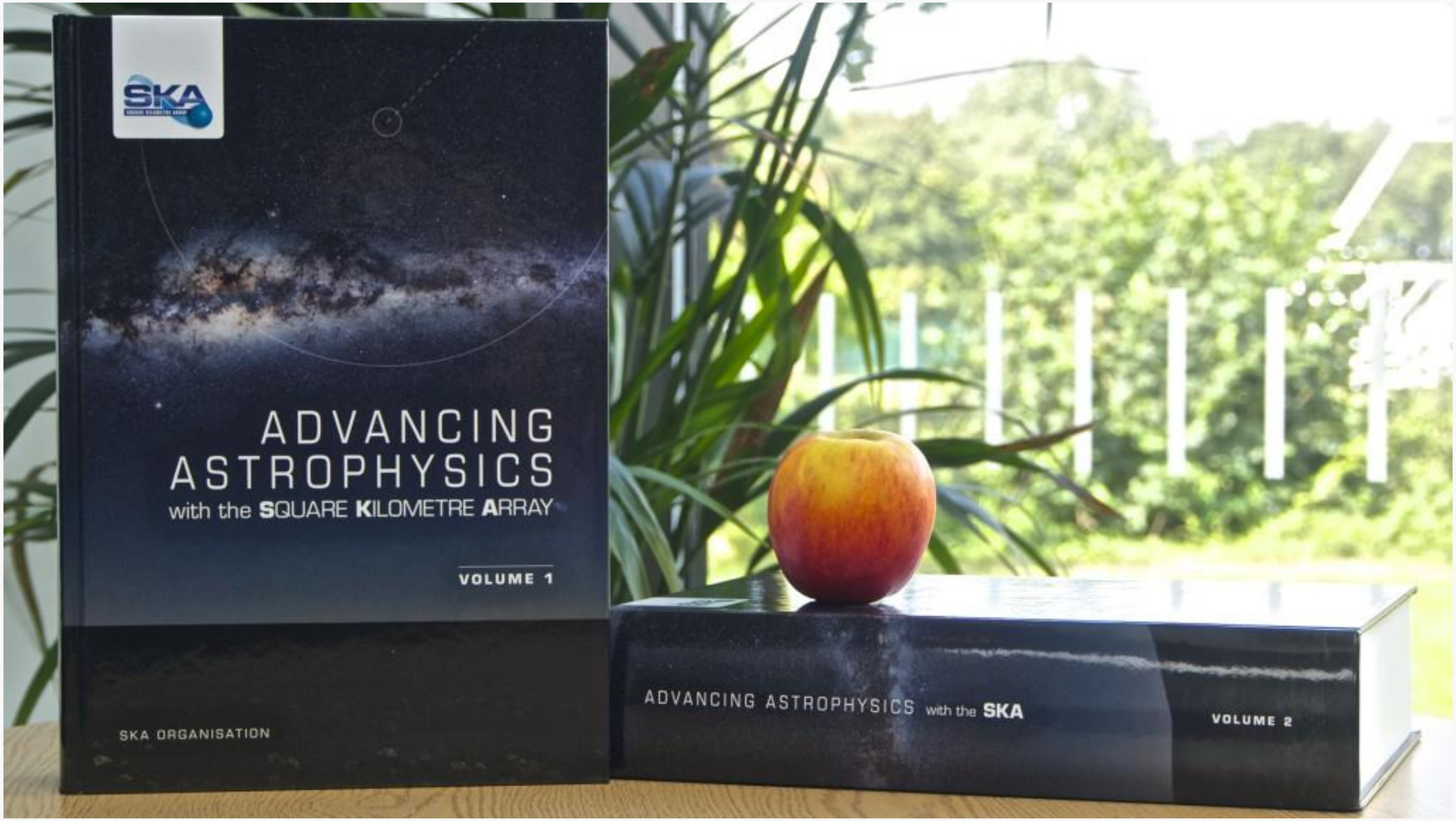
Resolution



LOFAR
SKA1−LOW
JVLA−A
ALMA−C2
SKA1−MID
SKA2
10
1
0.1
0.01
0.001
Resolution @ B_{Max} (arcsec)
0.1
1
10
100
1000
Frequency (GHz)

Science book 2015

2000 pages, 135 chapters, 1200 authors, 8.8 kg



http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=215

Science topics

Origin and Evolution of cosmic Magnetism
Epoch of Reionization
Cosmology and DE
HI galaxy science
Extragalactic spectral line
Extragalactic Continuum (galaxies/AGN, clusters)
Transients
Pulsars & Tests of Gravity
Our Galaxy
Solar, Heliosphere & Ionosphere Physics
Cradle of Life & Astrobiology

→ all-sky surveys, deep smaller-area surveys, targets

HI survey : 10^9 objects to $z \sim 2$
-> intensity mapping plus redshift

Continuum survey : 10^{10} objects to 100 nJy
-> 2 10^5 sources/deg^2

Sufficient source density and sky area to probe Cosmology, DM, DE

Polarization survey : RM of 10^7 objects
-> 300 sources/deg^2

High precision Magnetism from pc to Mpc

Pulsars : 30 000 → Physics, GW

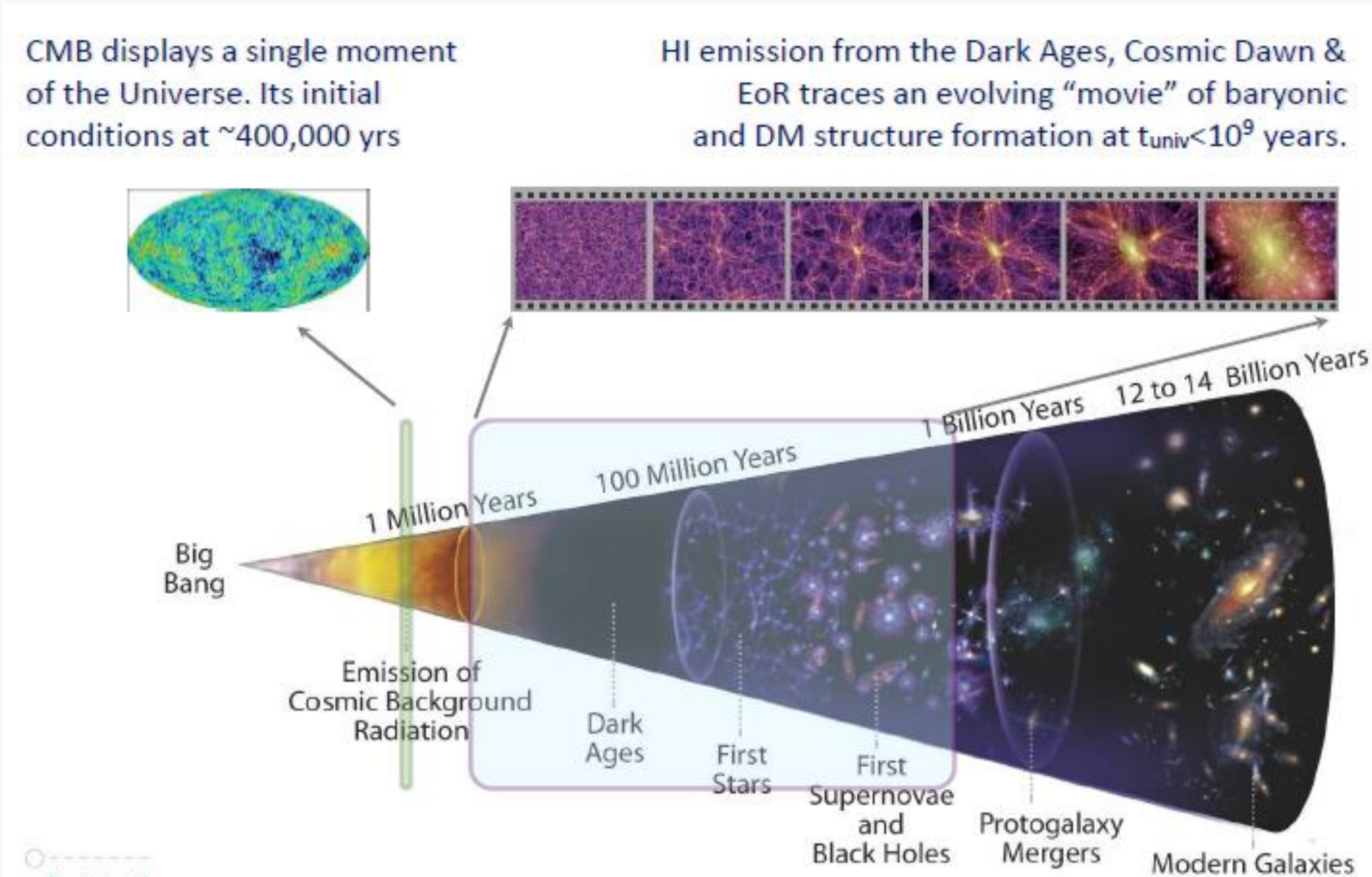
All objects that will be detected from currently planned all-sky surveys in X-rays, optical, infrared, will have **a radio counterpart** with SKA.

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.

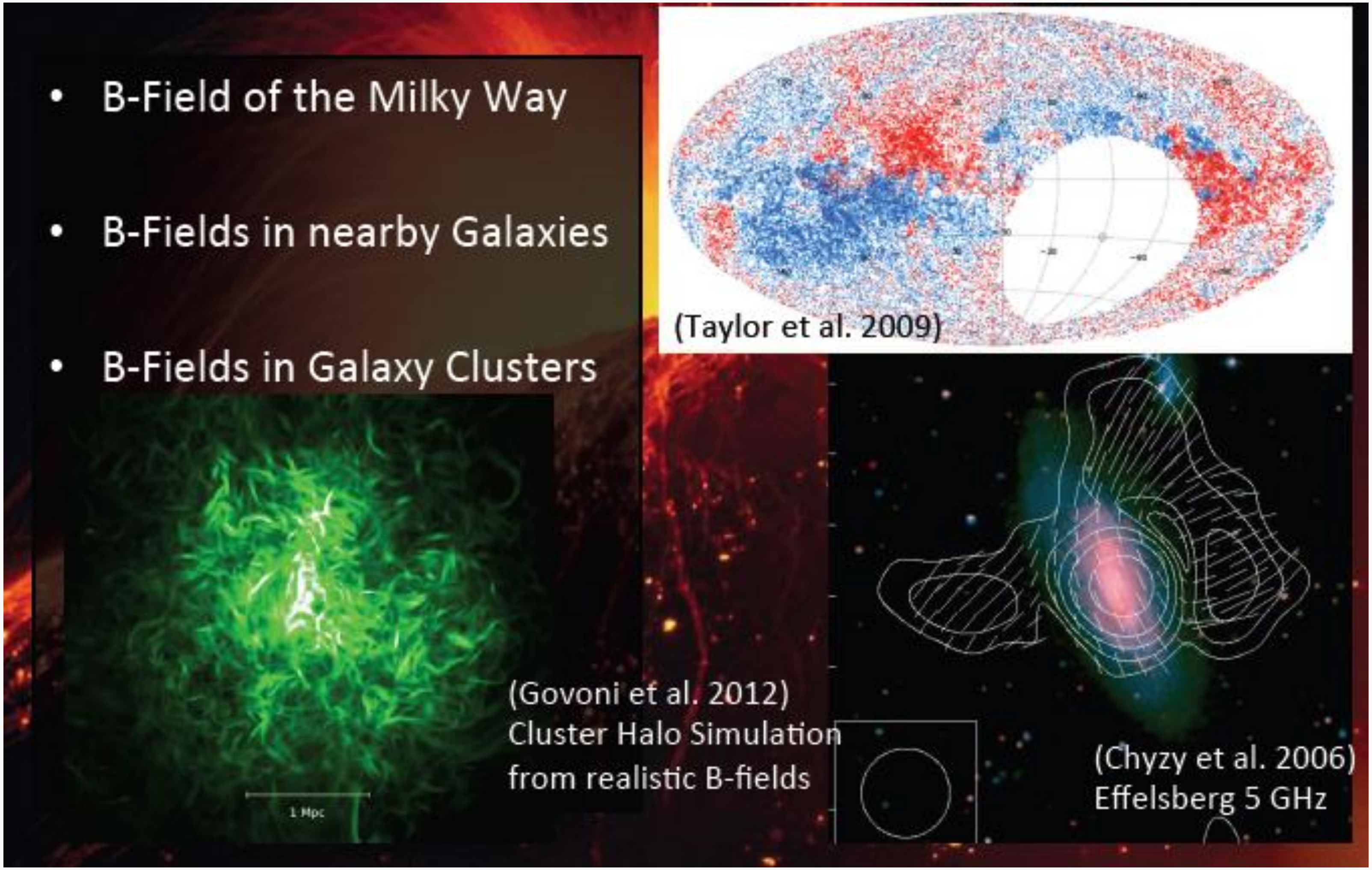
(Padovani 2010)

Epoch of Reionization

first signal will be likely detected in the next future,
SKA will go beyond detection, by imaging structure during
Reionization into Dark Ages

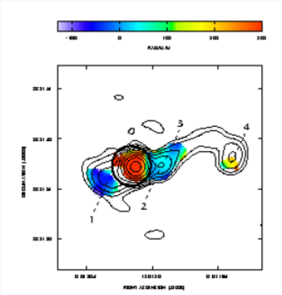


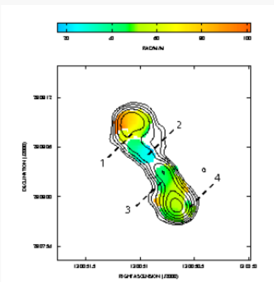
Magnetism

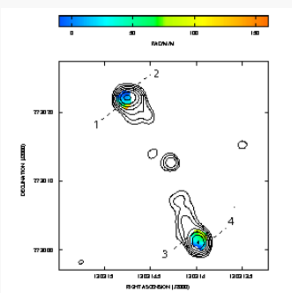

• B-Field of the Milky Way
• B-Fields in nearby Galaxies
• B-Fields in Galaxy Clusters
(Taylor et al. 2009)
1 Mpc
(Govoni et al. 2012)
Cluster Halo Simulation
from realistic B-fields
(Chyzy et al. 2006)
Effelsberg 5 GHz

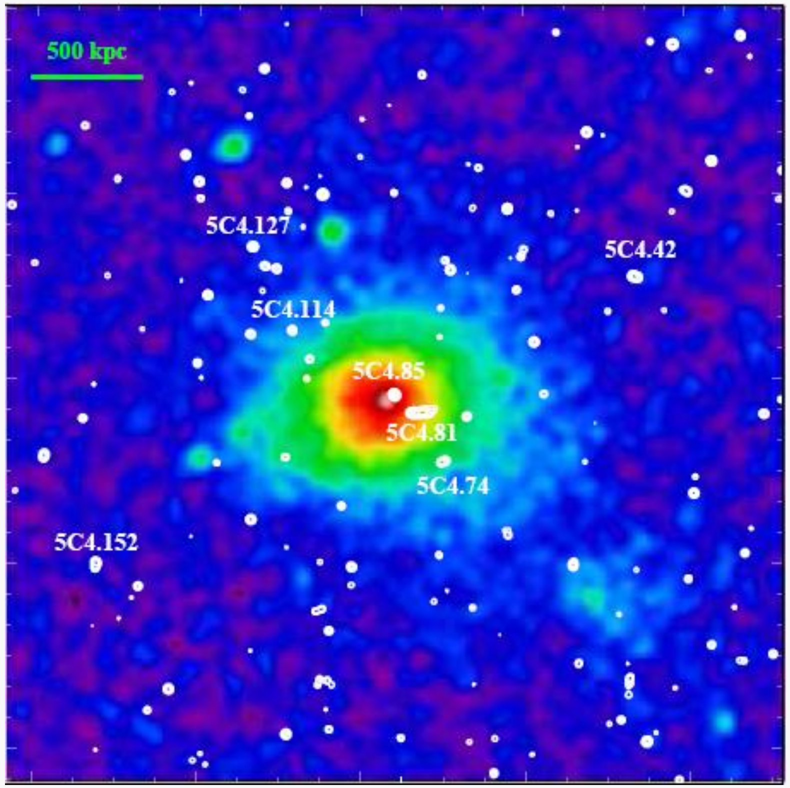
Coma Cluster

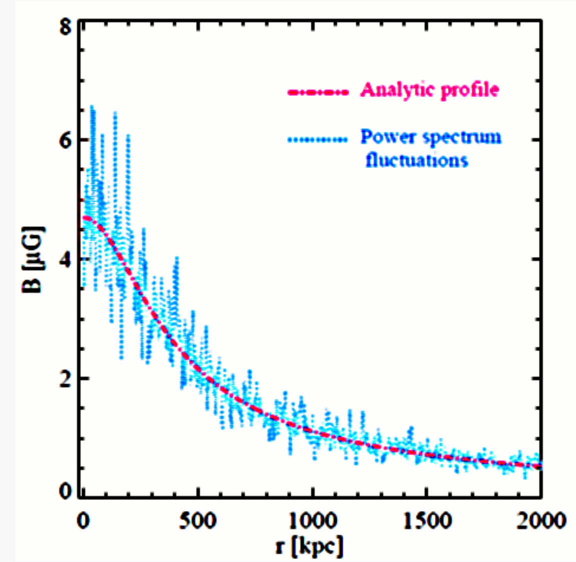
Bonafede et al. 2010



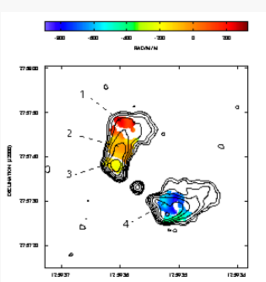


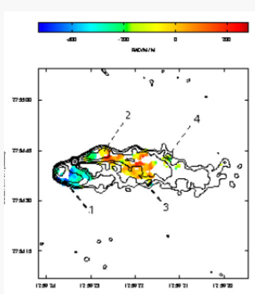


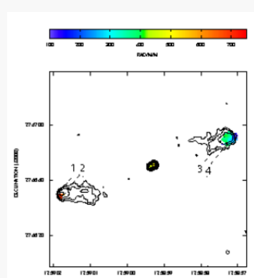


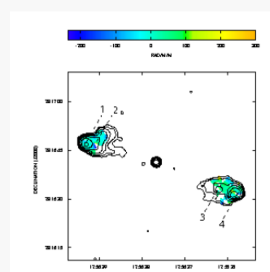


Magnetic field
- Strength
- Structure
- Radial decline









Currently with 7 sources

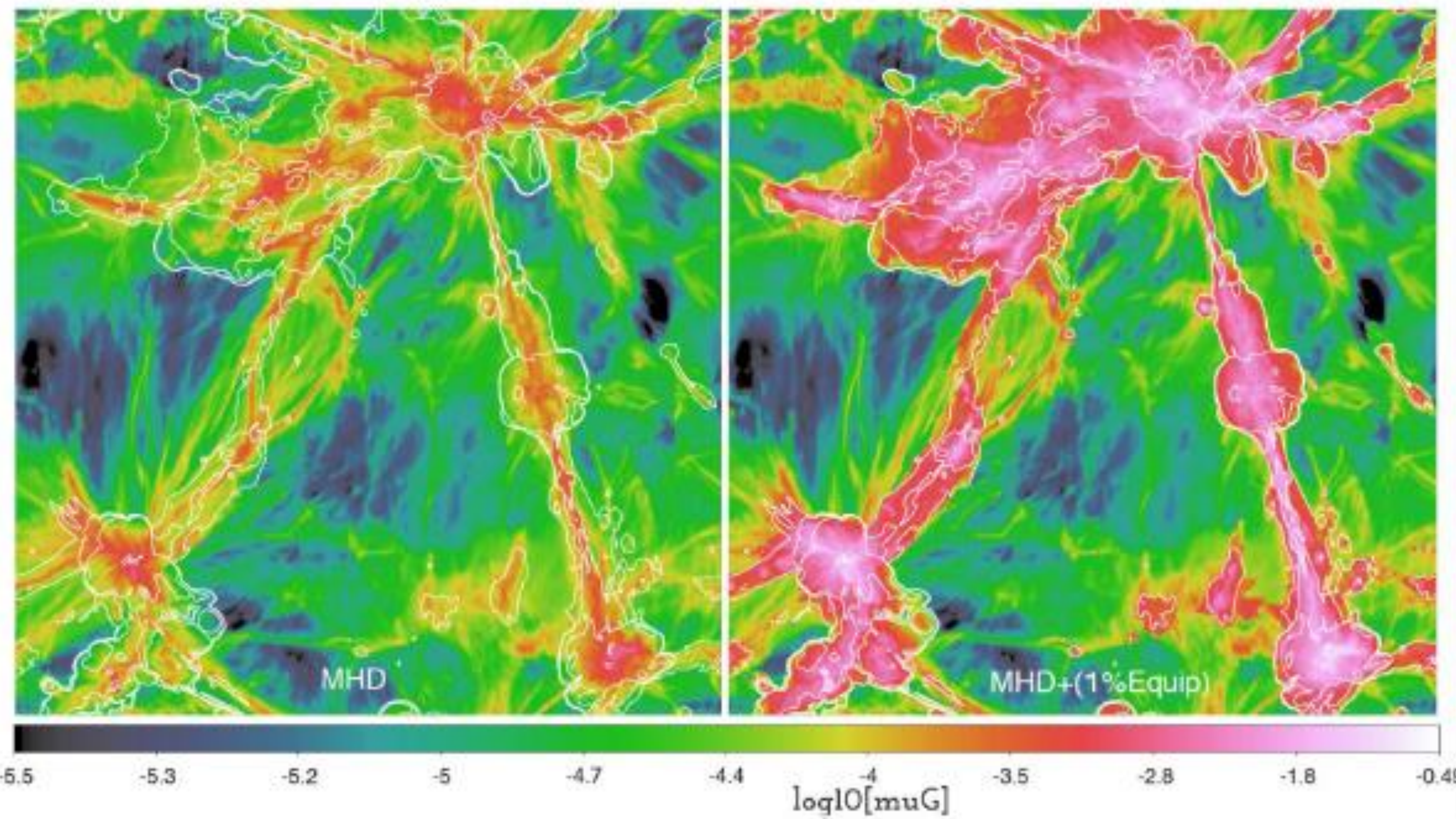
SKA ~1000 souces

➔Many clusters

➔Distant clusters

Understanding the origin and evolution of B fields

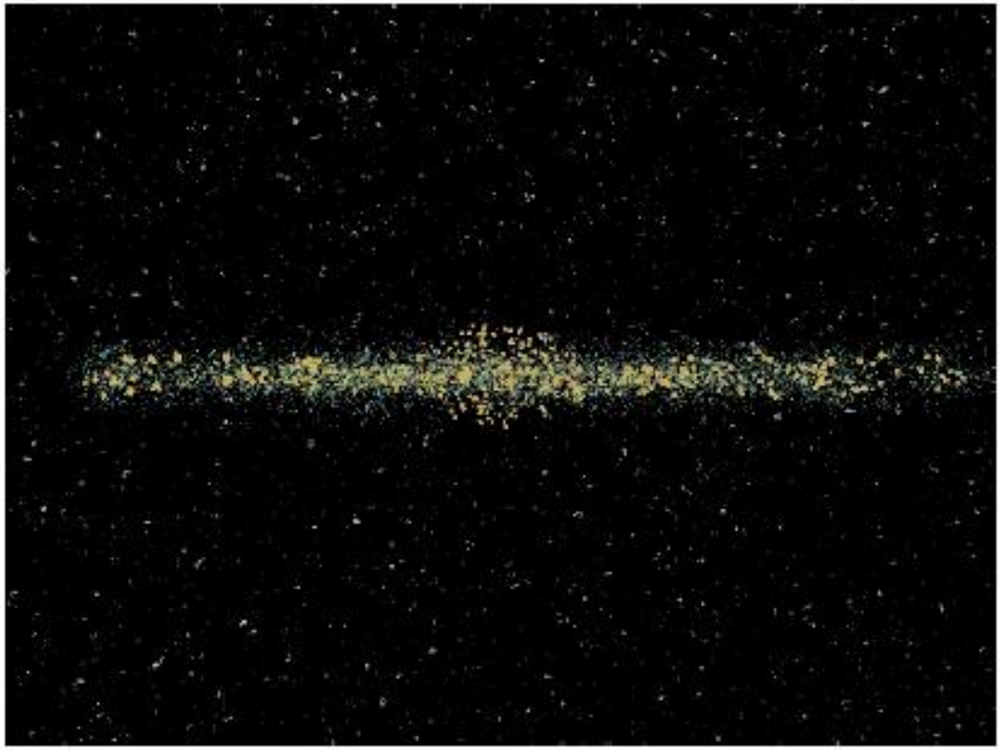
(Vazza et al. 2014)

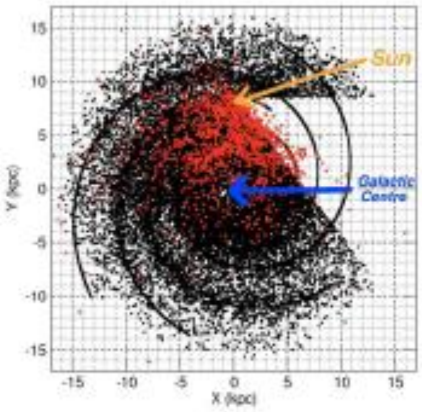


- Determine the role of magnetism in regulating galaxy evolution
- Detection and characterization of the magnetic cosmic web
- Magnetic evolution of AGN over cosmic time

Finding pulsars in the Milky Way

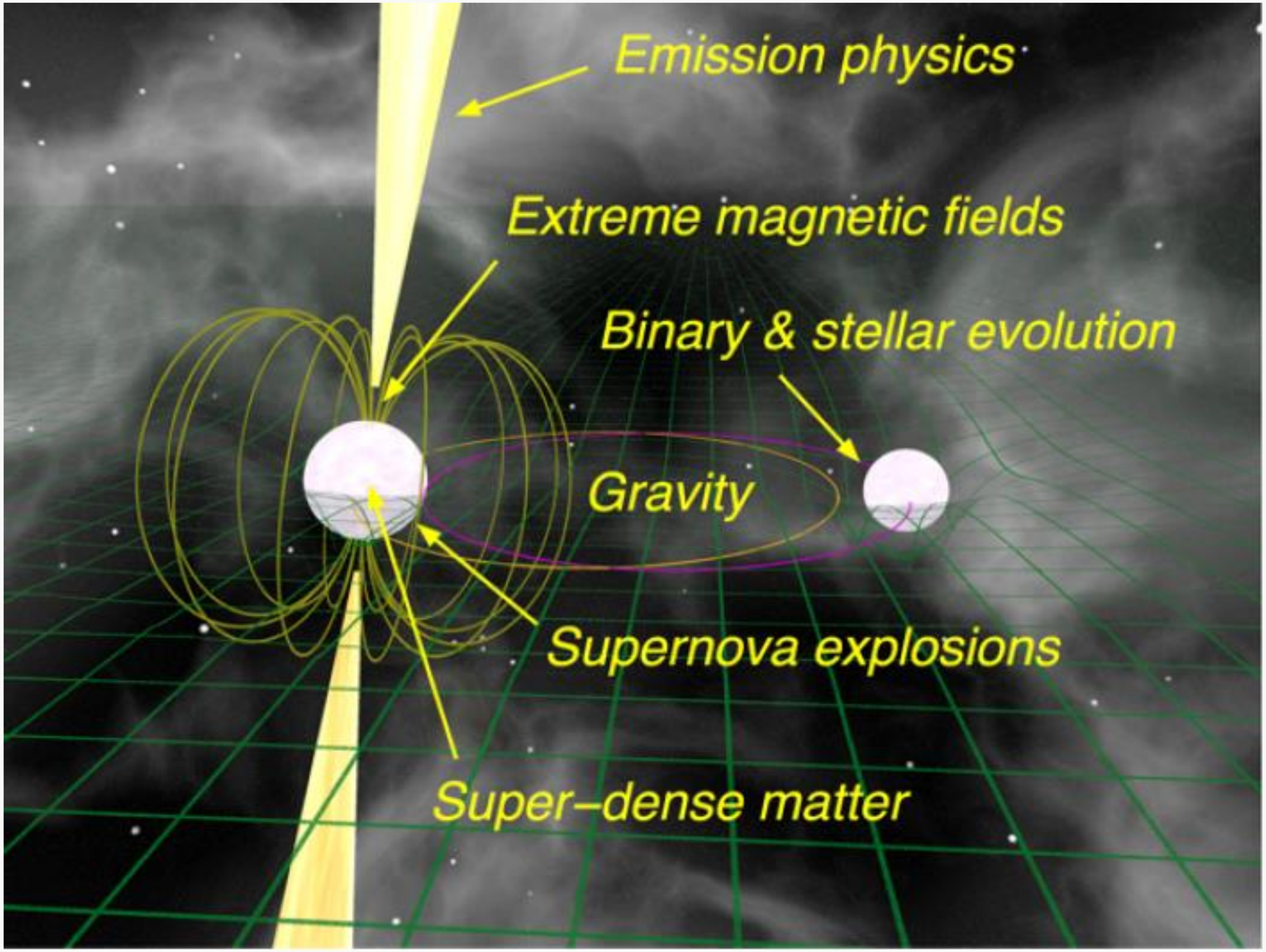
(Cordes et al. 2004, Kramer et al. 2004, Smits et al. 2008)





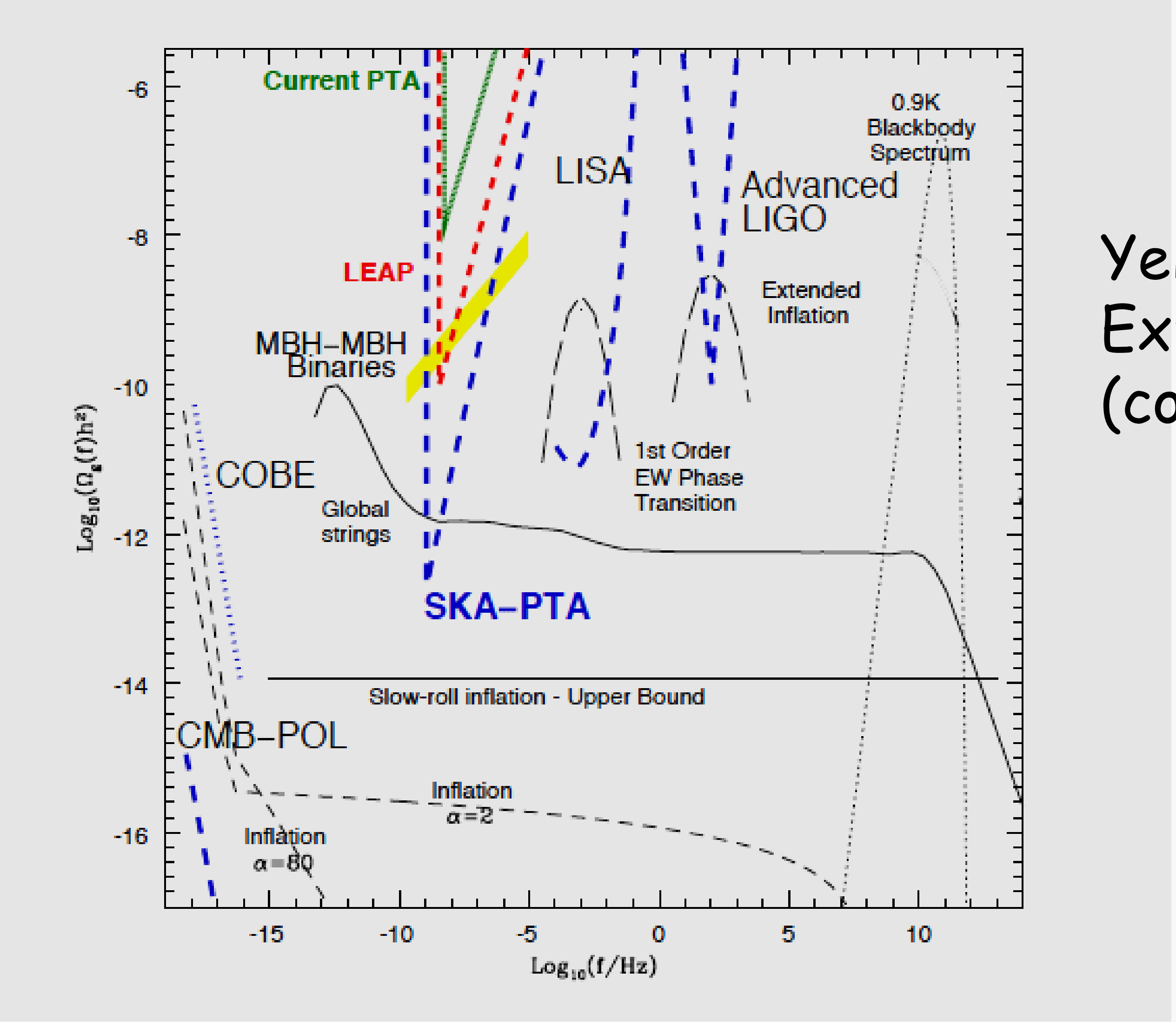
- ~30,000 normal pulsars
- ~2,000 millisecond psrs
- ~100 relativistic binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

- Timing precision is expected to increase by factor ~100
- Rare and exotic pulsars and binary systems: including PSR-BH systems!
- Testing cosmic censorship and no-hair theorem
- **Current estimates are that ~50% of entire Galactic population in reach of SKA1**



Physics and astrophysics applications from pulsar studies
(Kramer & Stappers 2014)

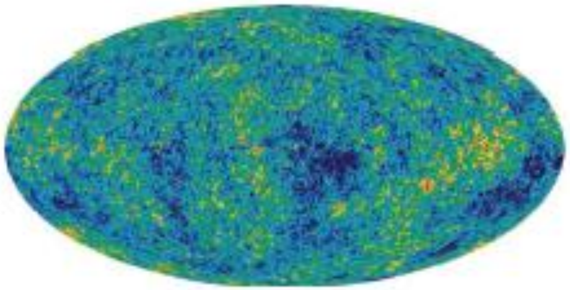
Gravity Wave detection

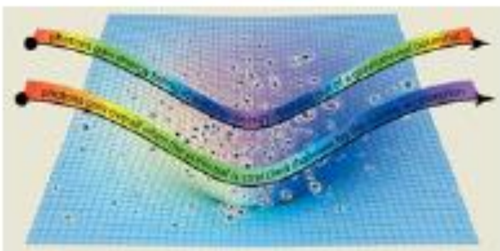


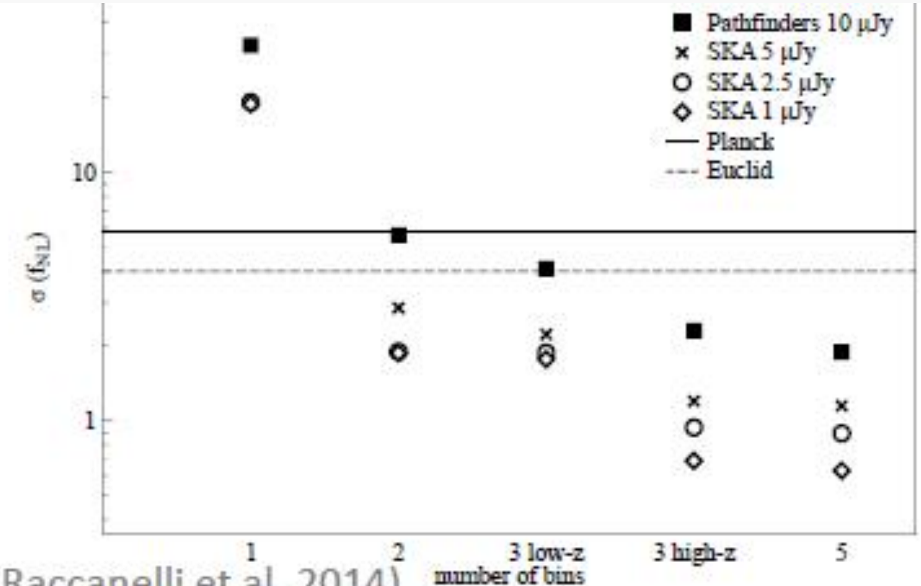
Yellow:
Expected background (coalescing of MBH)

(Carilli 2014)

Cosmology





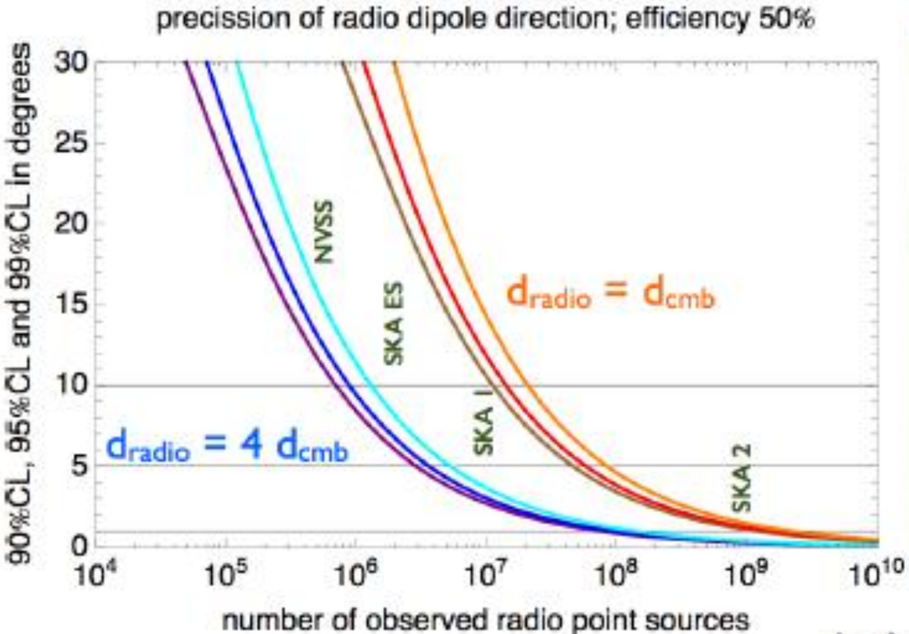


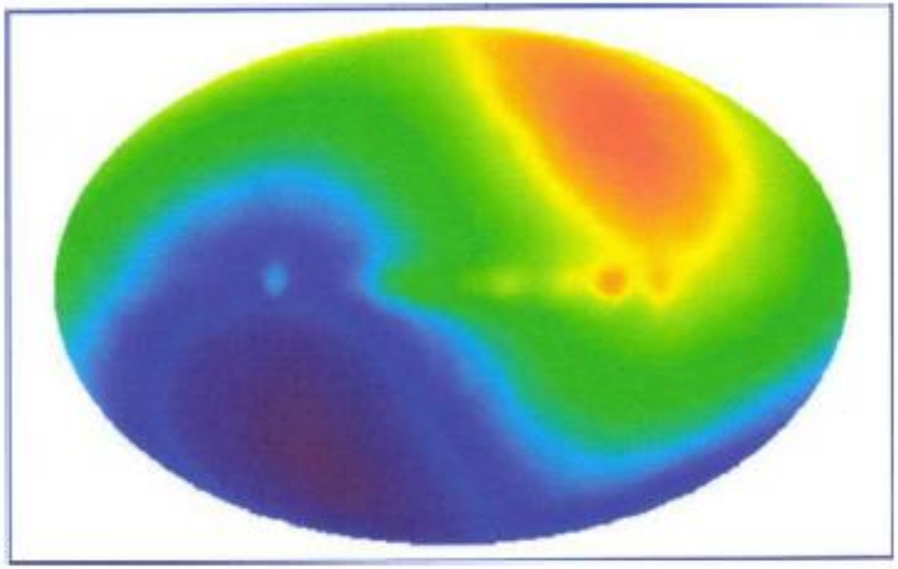
(Raccanelli et al. 2014)

- Constraining non-Gaussianity of primordial fluctuations with the Integrated Sachs-Wolfe effect: correlation of foreground source populations with CMB structures
  - Uniquely probing the largest scales

Baryon Acoustic Oscillations to constrain DE models

Matter Dipole versus CMB Dipole

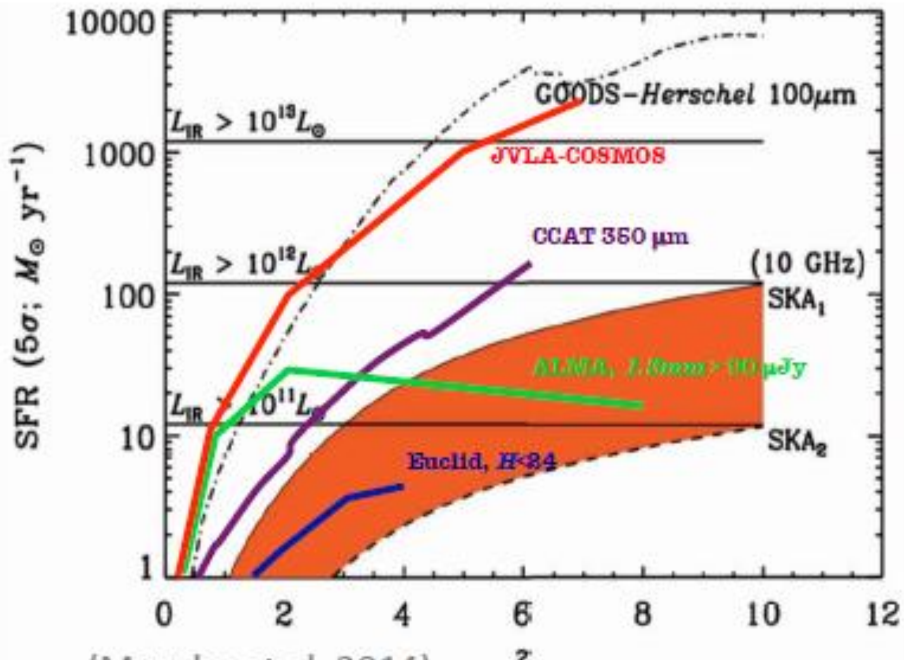




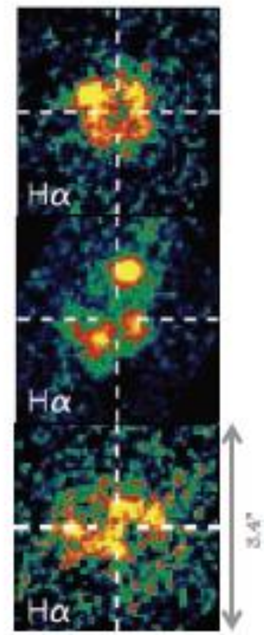
(Schwarz et al. 2014)

- Sensitive constraints on isotropy and homogeneity
  - Unique tests of isotropy at z ~ 1
  - Measure cosmic matter dipole with high precision

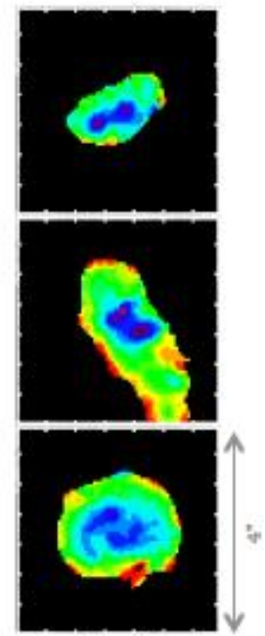
Galaxy evolution: star formation history
Star forming galaxies at z ~ 7 to 10



(Murphy et al. 2014)



Wuyts et al 2013, z~1
Hα–based SFR-maps



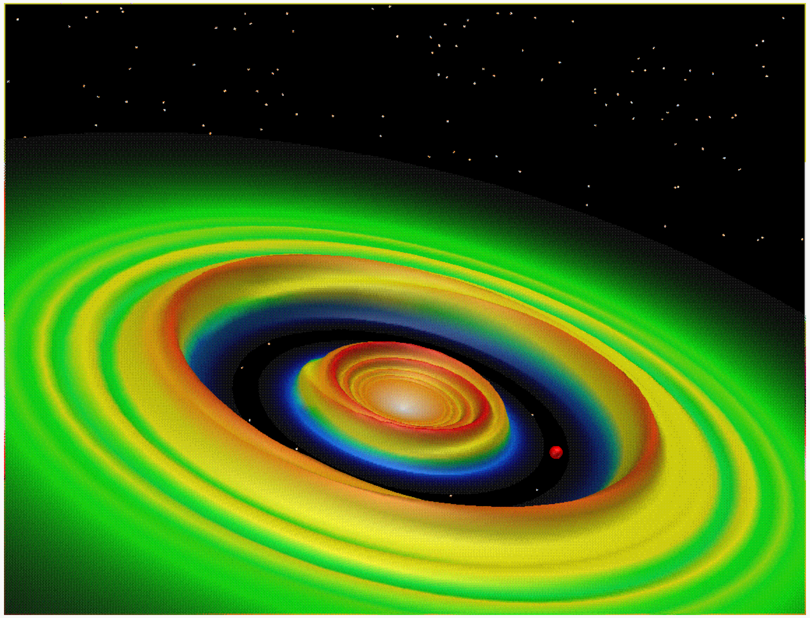
Cibinel et al 2014, z~2
UV-based SFR-maps

- Unmatched sensitivity to star formation rates (10 $M_\odot$/yr) out to z ~ 4
- Resolved (sub-kpc) imaging of star forming disks out to z ~ 1

The Cradle of Life

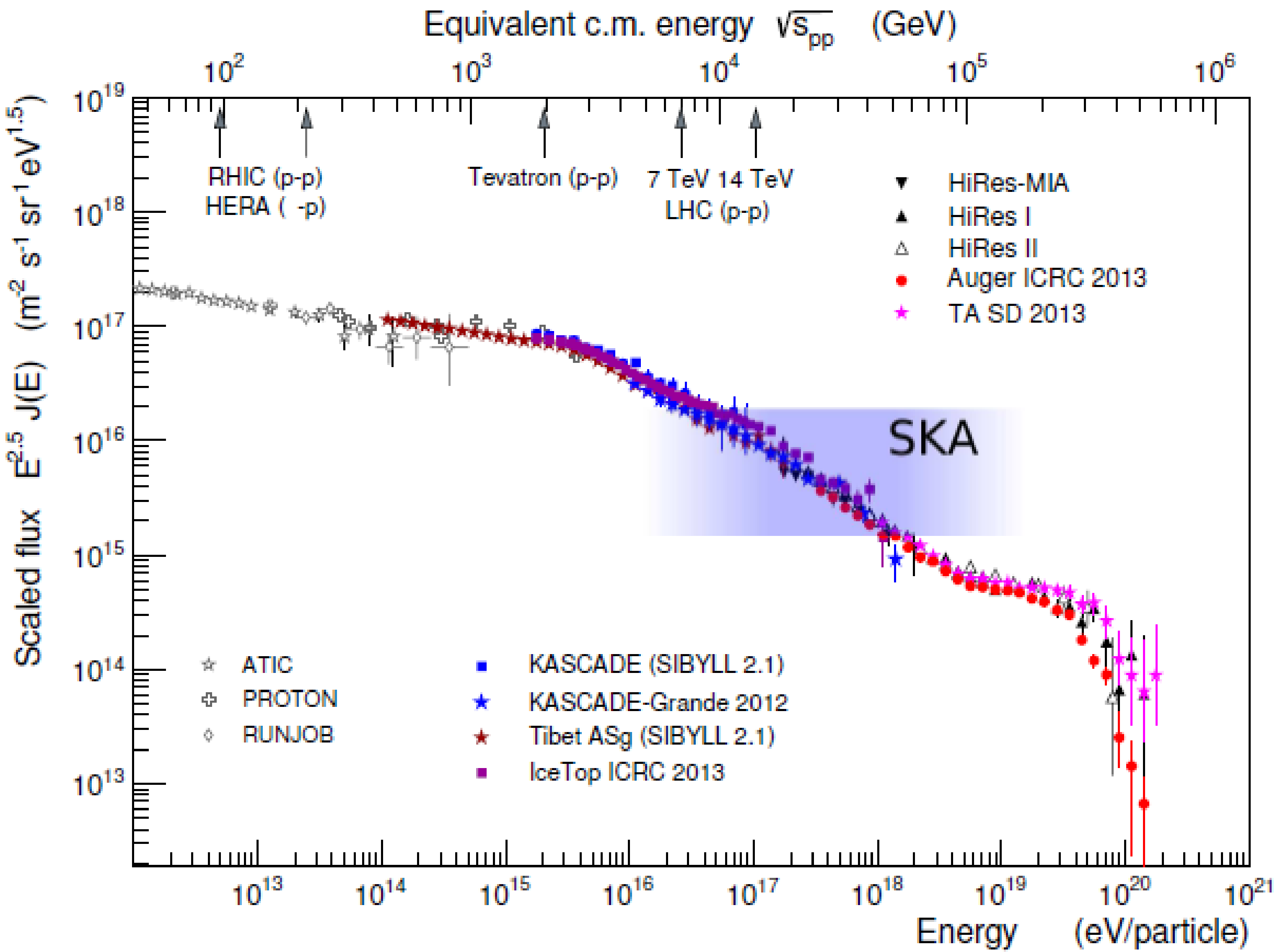
Test conditions for life elsewhere in the Universe

- 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 @ 15 pc → 1 000 stars, many with planets

Cosmic rays



Huege et al. 2015

Science topics

Origin and Evolution of cosmic Magnetism
Epoch of Reionization
Cosmology and DE
HI galaxy science
Extragalactic spectral line
Extragalactic Continuum (galaxies/AGN, clusters)
Transients
Pulsars & Tests of Gravity
Our Galaxy
Solar, Heliosphere & Ionosphere Physics
Cradle of Life & Astrobiology

Conclusion : Transformational science in all fields !

Thanks

Headline Science with SKA 1 and 2

	SKA1	SKA2
The Cradle of Life & Astrobiology	Proto-planetary disks; imaging inside the 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	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 ~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	The role of magnetism from sub-galactic to Cosmic Web scales, the RM-grid @ 300/deg2.	The origin and amplification of cosmic magnetic fields, the RM-grid @ 5000/deg2.
	Faraday tomography of extended sources, 100pc resolution at 14Mpc, 1 kpc @ z ≈ 0.04.	Faraday tomography of extended sources, 100pc resolution at 50Mpc, 1 kpc @ z ≈ 0.13.
Galaxy Evolution probed by Neutral Hydrogen	Gas properties of 10^7 galaxies, <z> ≈ 0.3, evolution to z ≈ 1, BAO complement to Euclid.	Gas properties of 10^9 galaxies, <z> ≈ 1, evolution to z ≈ 5, world-class precision cosmology.
	Detailed interstellar medium of nearby galaxies (3 Mpc) at 50pc resolution, diffuse IGM down to N_H < 10^17 at 1 kpc.	Detailed interstellar medium of nearby galaxies (10 Mpc) at 50pc resolution, diffuse IGM down to N_H < 10^17 at 1 kpc.

	SKA1	SKA2
The Transient Radio Sky	Use fast radio bursts to uncover the missing "normal" matter in the universe.	Fast radio bursts as unique probes of fundamental cosmological parameters and intergalactic magnetic fields.
	Study feedback from the most energetic cosmic explosions and the disruption of stars by super-massive black holes.	Exploring the unknown: new exotic astrophysical phenomena in discovery phase space.
Galaxy Evolution probed in the Radio Continuum	Star formation rates (10 M_Sun/yr to z ~ 4).	Star formation rates (10 M_Sun/yr to z ~ 10).
	Resolved star formation astrophysics (sub-kpc active regions at z ~ 1).	Resolved star formation astrophysics (sub-kpc active regions at z ~ 6).
Cosmology & Dark Energy	Constraints on DE, modified gravity, the distribution & evolution of matter on super-horizon scales: competitive to Euclid.	Constraints on DE, modified gravity, the distribution & evolution of matter on super-horizon scales: redefines state-of-art.
	Primordial non-Gaussianity and the matter dipole: 2x Euclid.	Primordial non-Gaussianity and the matter dipole: 10x Euclid.
Cosmic Dawn and the Epoch of Reionization	Direct imaging of EoR structures (z = 6 - 12).	Direct imaging of Cosmic Dawn structures (z = 12 - 30).
	Power spectra of Cosmic Dawn down to arcmin scales, possible imaging at 10 arcmin.	First glimpse of the Dark Ages (z > 30).