The Square Kilometre Array: Science

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DARA Nairobi
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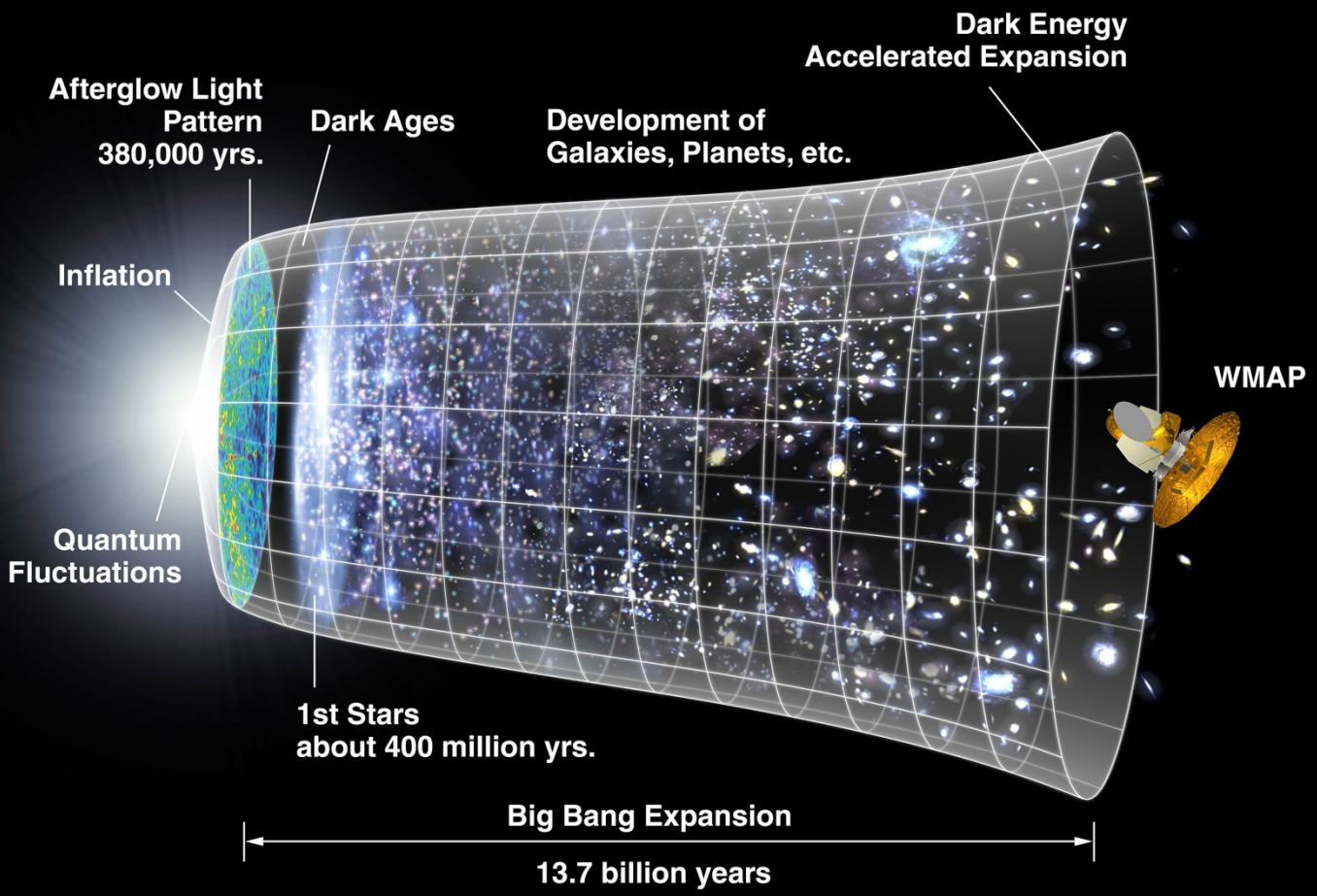
What will the SKA do?

History of the Universe



SKA Key Science Drivers

ORIGINS

- **History of Universe in neutral hydrogen**

  Probing dark ages: When did first stars and galaxies form?
  Epoch of re-ionisation, cosmic dawn
  How did galaxies evolve?
  Cosmology, Dark Energy, Dark Matter

- **Stars, planets and life**

  Astro-biology - protplanetary disks

FUNDAMENTAL FORCES

- **Pulsars, General Relativity & gravitational waves**

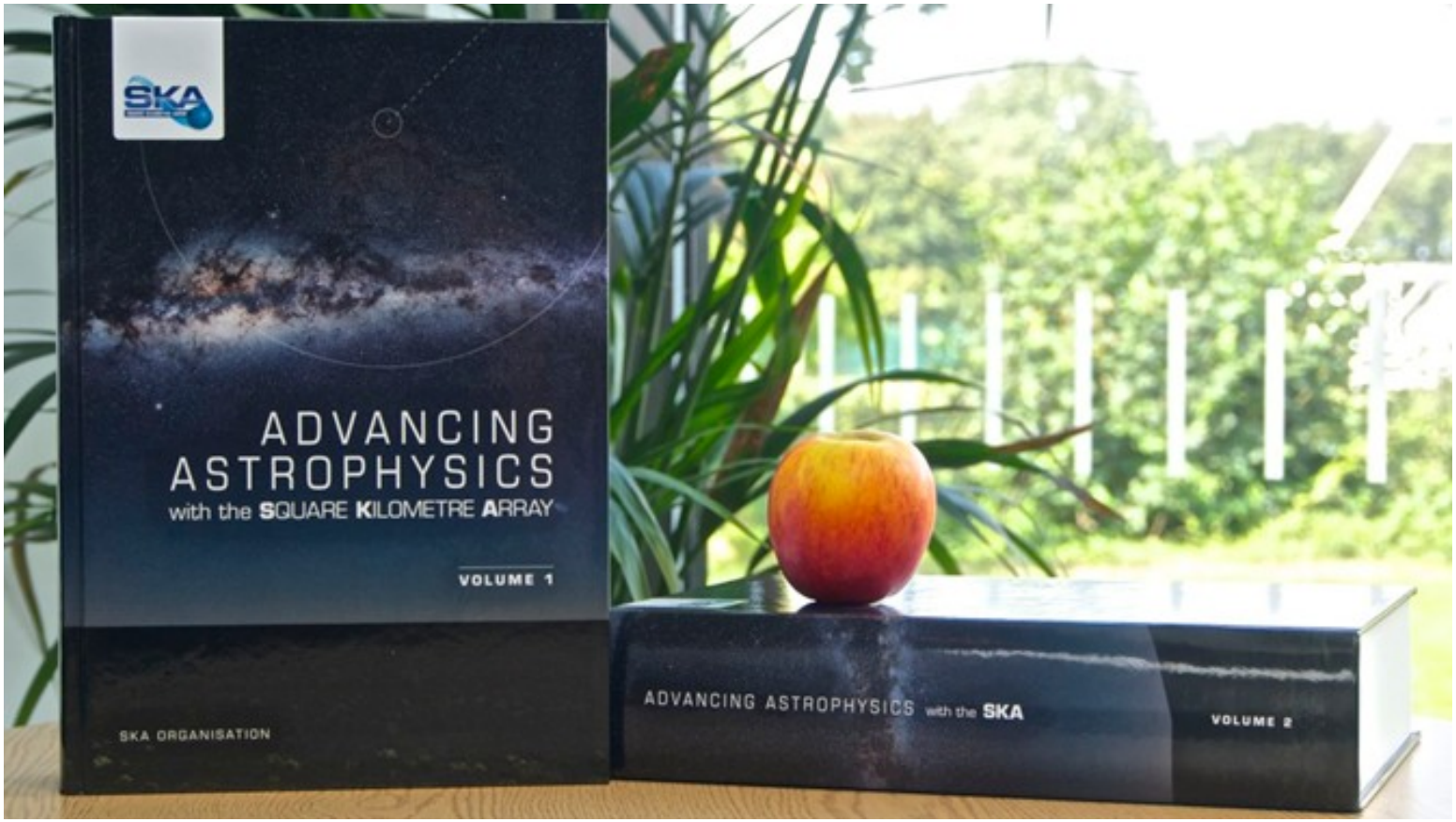
- **Origin & evolution of cosmic magnetism**

NEW PHENOMENA (EXPLORATION OF THE UNKNOWN)

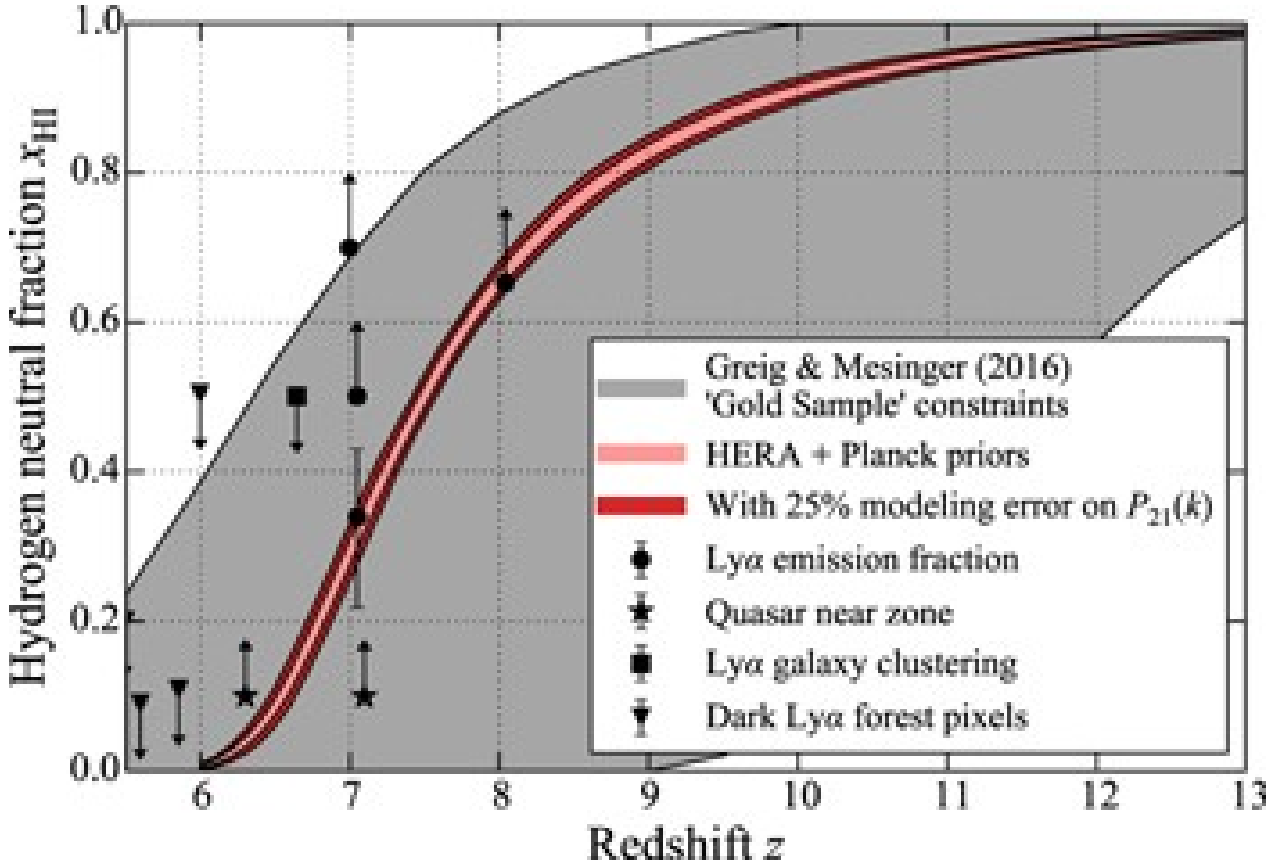
- **Transients, fast radio bursts (FRBs)**

SKA science papers

- https://www.skatelescope.org/books/



Cosmic Origins
Ionisation as a function of redshift



The interesting range of redshifts is from ~6 to ~12

HERA (Hydrogen Epoch of Reionisation Array)

David R. DeBoer et al. 2017 PASP 129 045001 doi:10.1088/1538-3873/129/974/045001

Cosmic Origins:
Probing early universe with 21cm HI Line

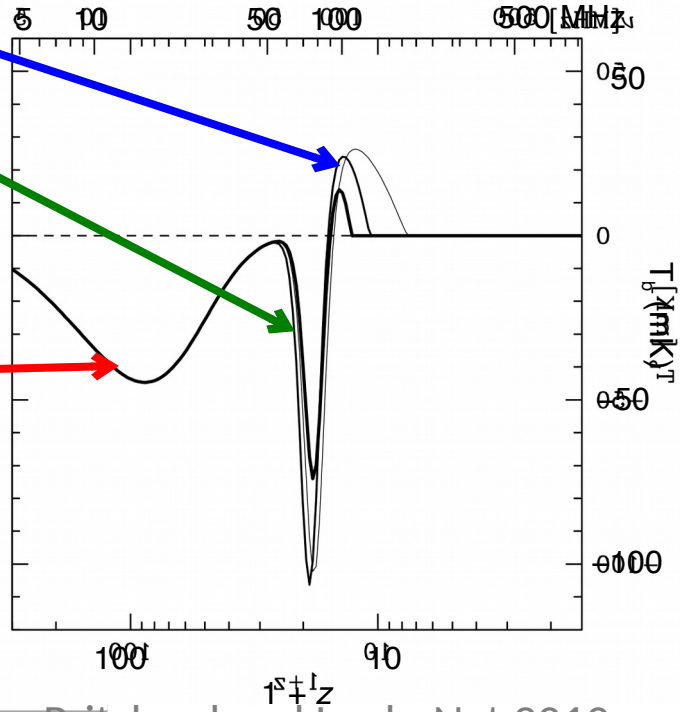
Neutral Hydrogen 21 cm spin-flip transition provides probe of neutral intergalactic medium before and during formation of first stars.

"HI Forest" towards high-z sources.

EoR

Cosmic Dawn

Dark Ages

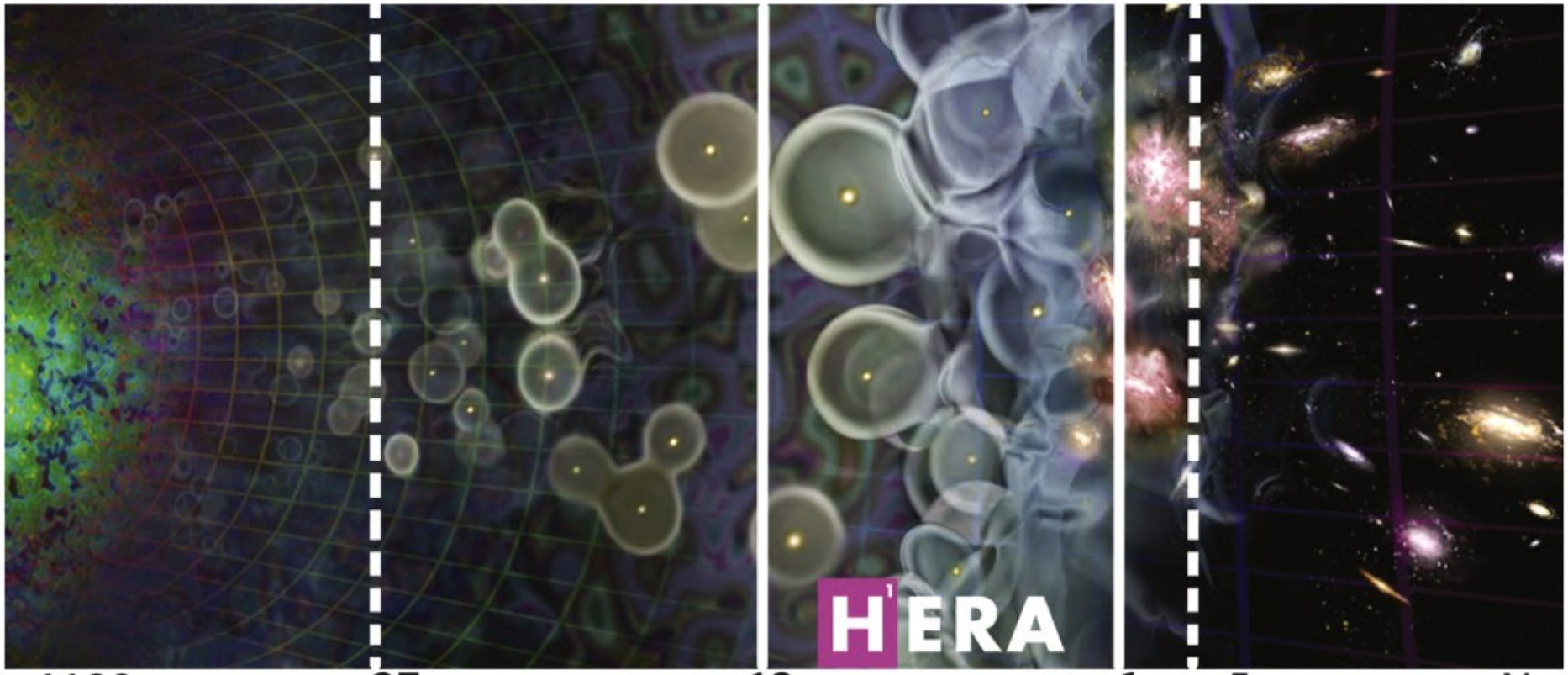


$\nu = 1420 \text{ MHz}/(1 + z)$

$\lambda = 21 \text{ cm } (1 + z)$

Pritchard and Loeb, Nat 2010

Epoch of re-ionisation

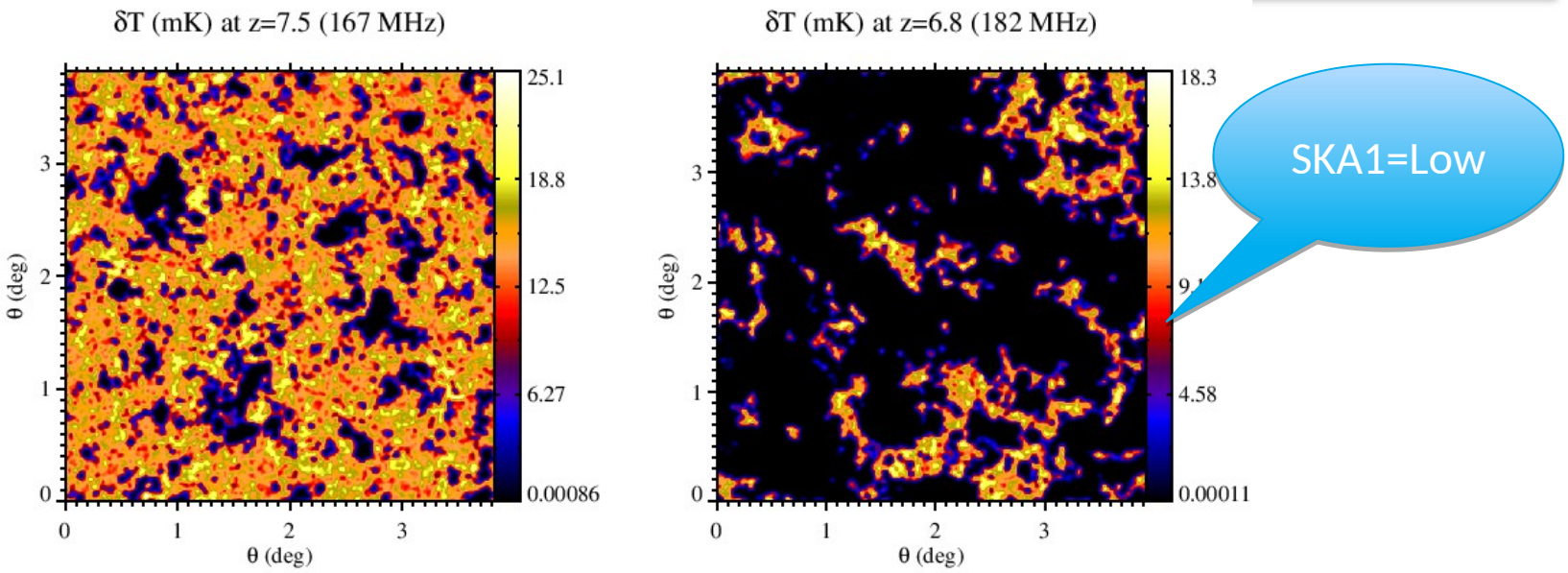


z=1100	z=27	z=13	z=6	z=5	Now
CMB	50 MHz	100 MHz	200 MHz	225 MHz	
400kyr	164Myr	370Myr	1Gyr	1.1Gyr	

Exploring the Universe with the world's largest radio telescope

background image credit Loeb/*Scientific American*).

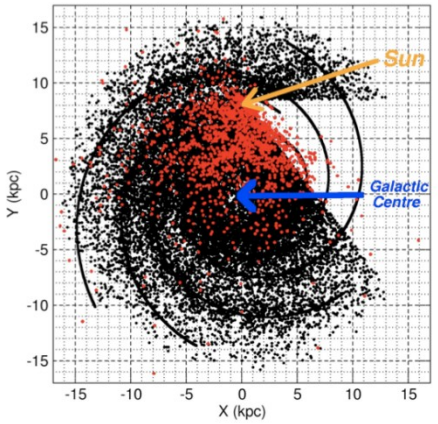
HI surveys of the EoR/Cosmic-Dawn Universe



- Detecting EoR structures in imaging mode (as distinct from statistically) on 5 arcmin scales with 1 mK RMS
- Probing the Cosmic Dawn statistically or possibly even imaging

Finding all pulsars in the Milky Way…
Huge pulsar surveys - pulsar black hole binaries
Direct tests of gravity in the strong field limit.

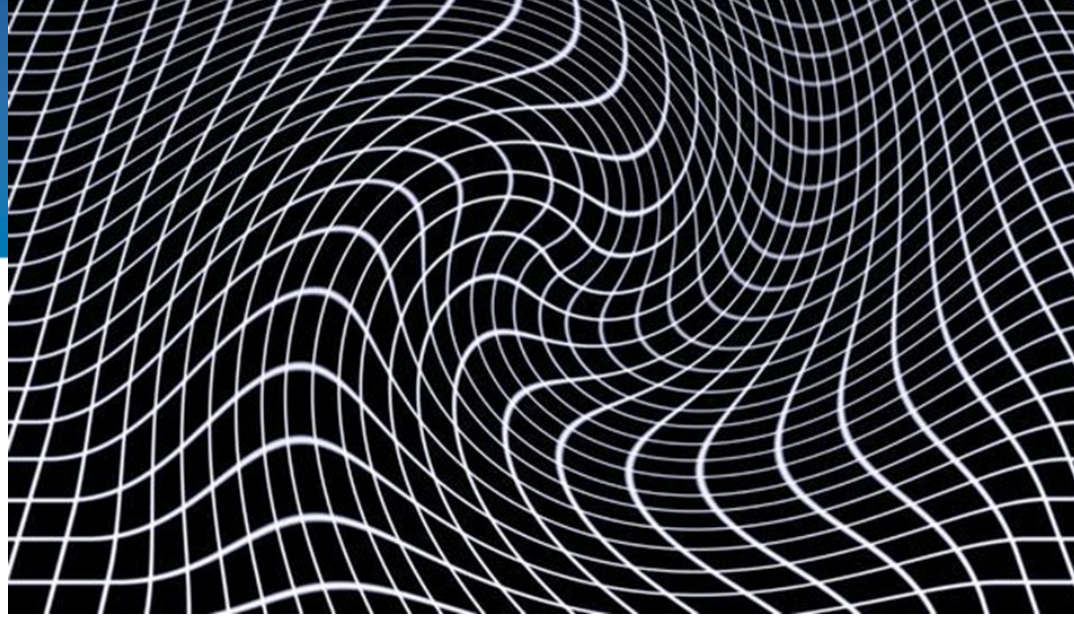
(Cordes et al. 2004, Kramer et al. 2004, Smits et al. 2008)

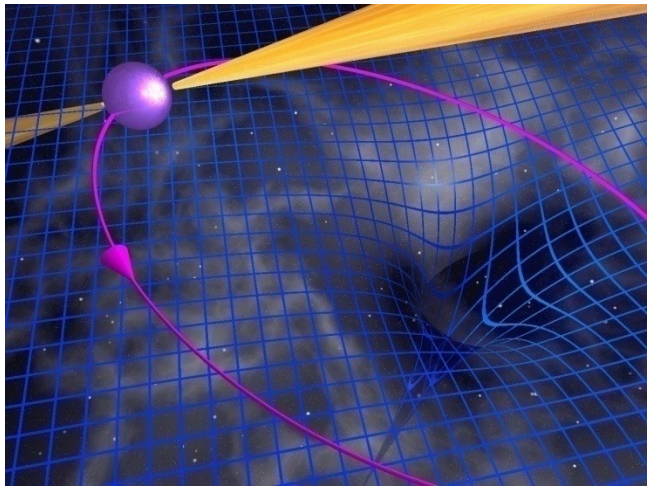


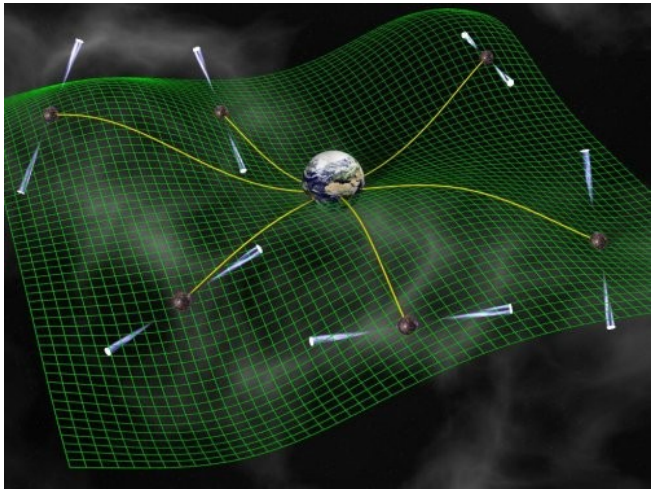
- ~30,000 normal pulsars
- ~2,000 millisecond psrs
- ~100 relativistic binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

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

Tests of General Relativity and Search for Gravitational Waves

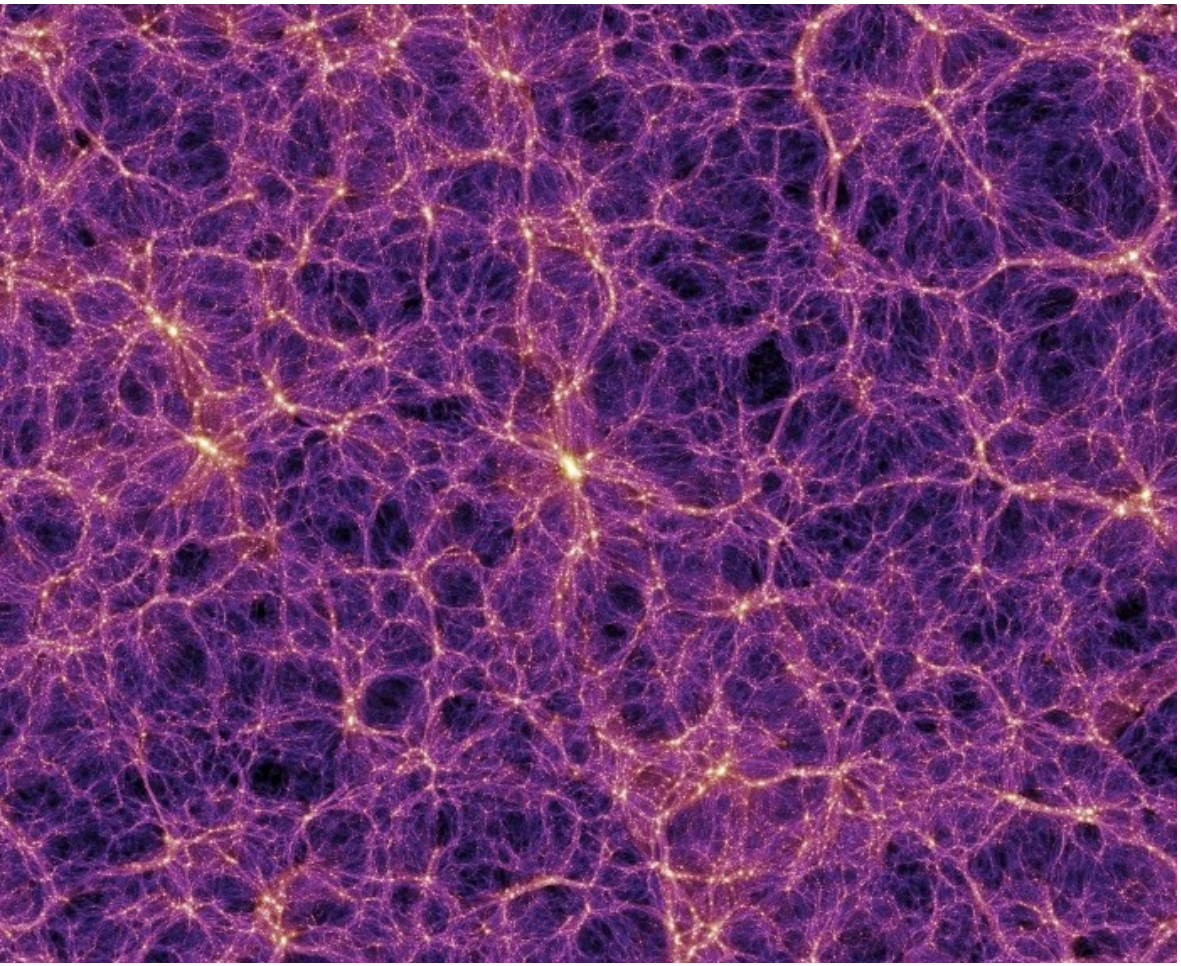






- Pulsars orbiting supermassive (10^6 solar mass) black hole at Galactic Centre
- Network of millisec pulsars provide an array of very stable “clocks” which can be used to detect a background of gravitational waves.

The Nature of Dark Energy and Testing Einstein's Gravity



Measure one billion galaxy locations in 3-D

Clues to the nature of the dark energy - modifications of General Relativity.

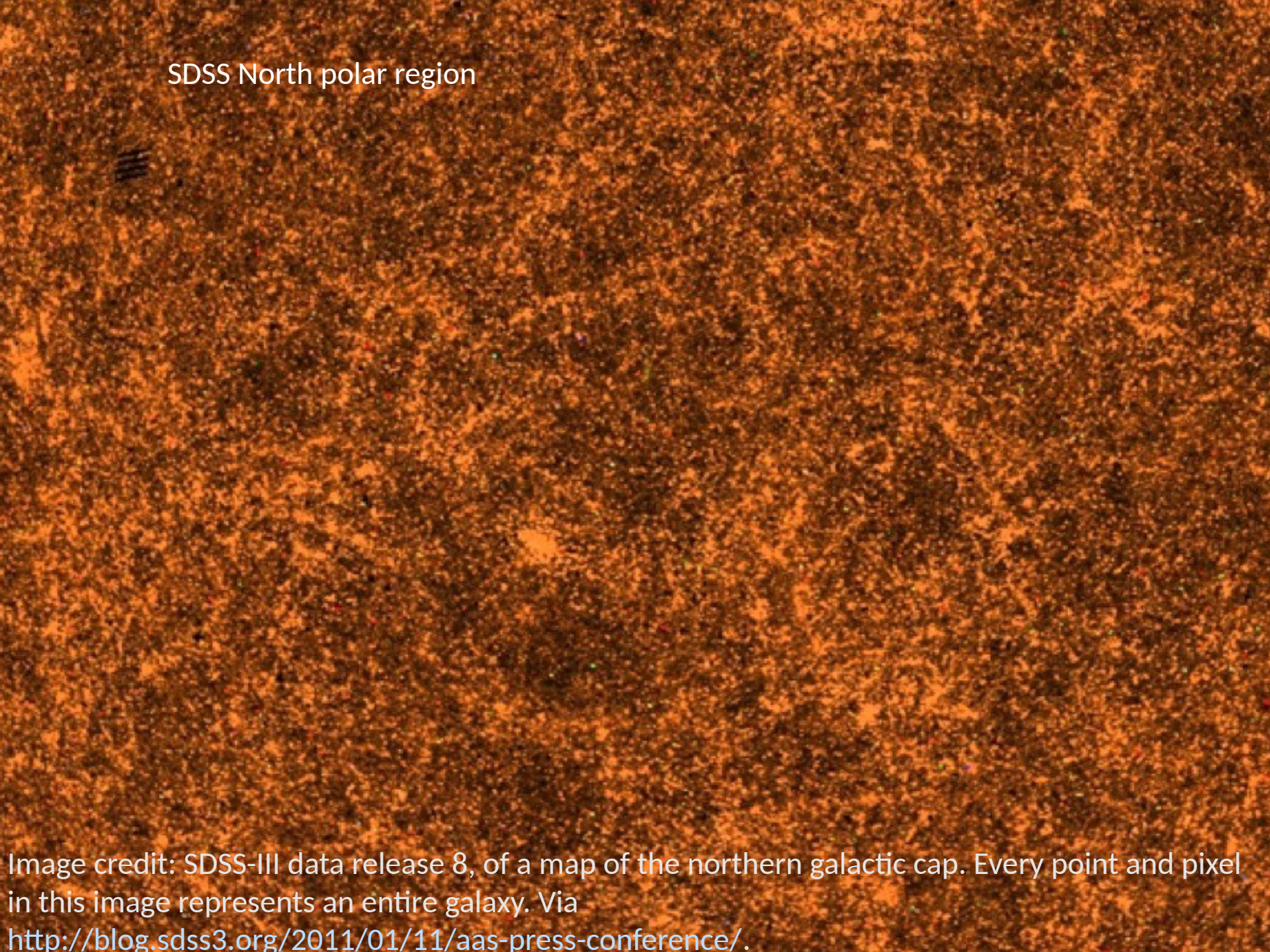
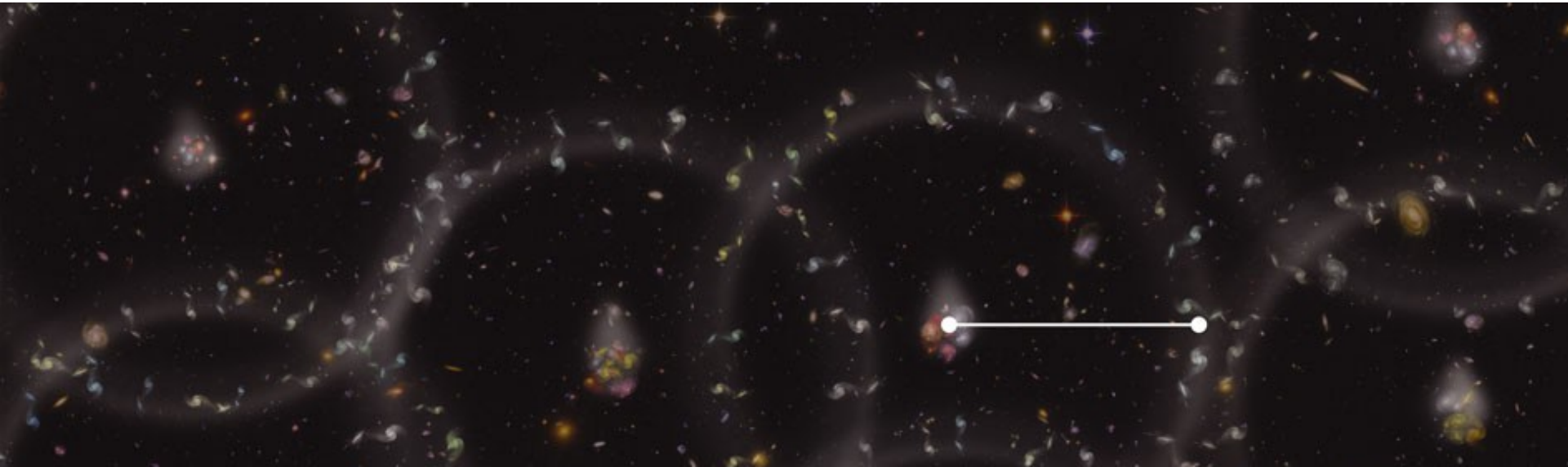


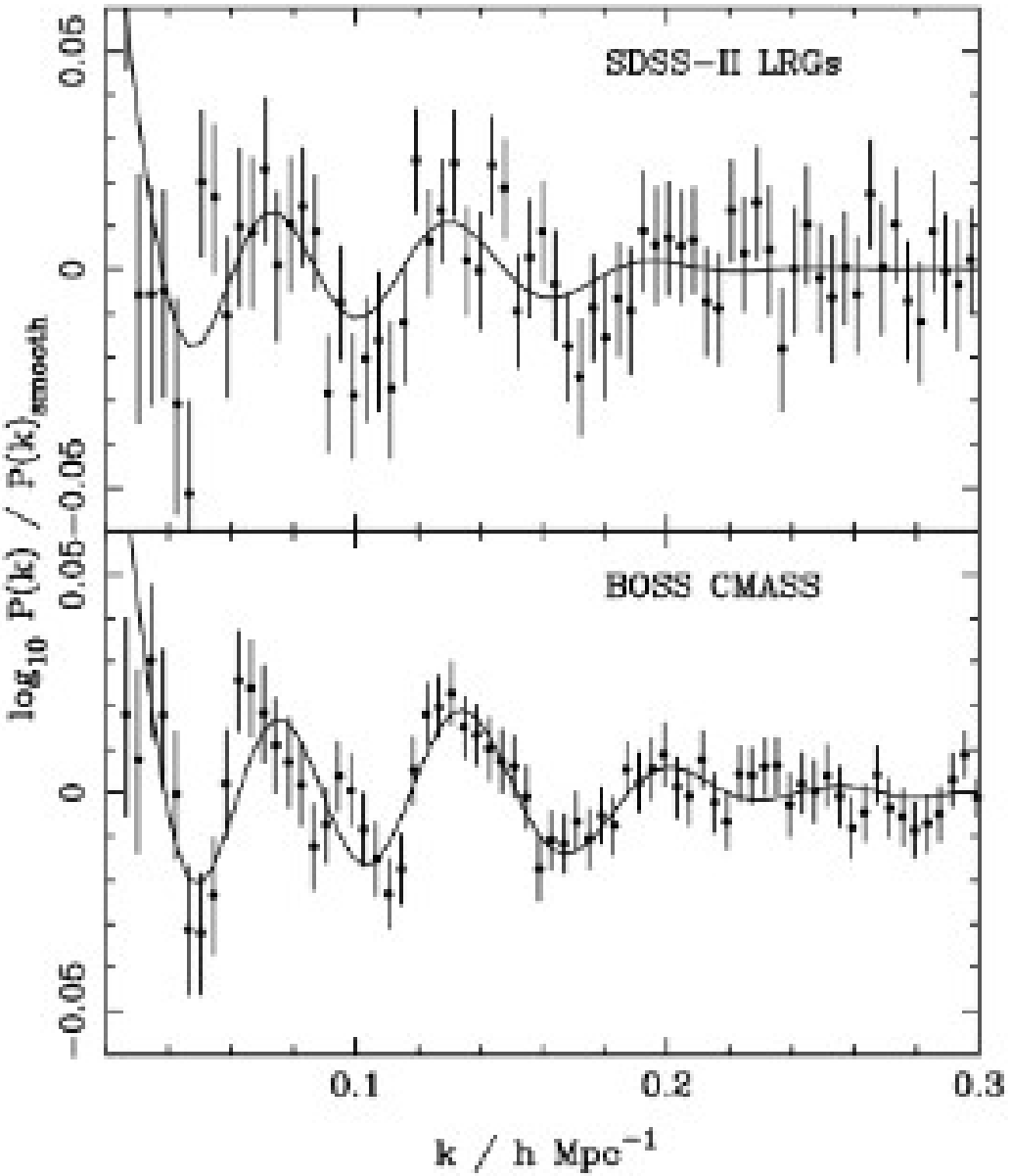
Image credit: SDSS-III data release 8, of a map of the northern galactic cap. Every point and pixel in this image represents an entire galaxy. Via http://blog.sdss3.org/2011/01/11/aas-press-conference/.

Baryon Acoustic Oscillations

- Sound waves propagate in early universe, like spreading ripples in a pond
- Waves imprint characteristic scale on cosmic microwave background (CMB) fluctuations
- Fluctuations have evolved into today's walls and voids of galaxies, meaning this baryon acoustic oscillation (BAO) scale (about 150 Mpc) is visible among galaxies today



Baryon Acoustic Oscillations

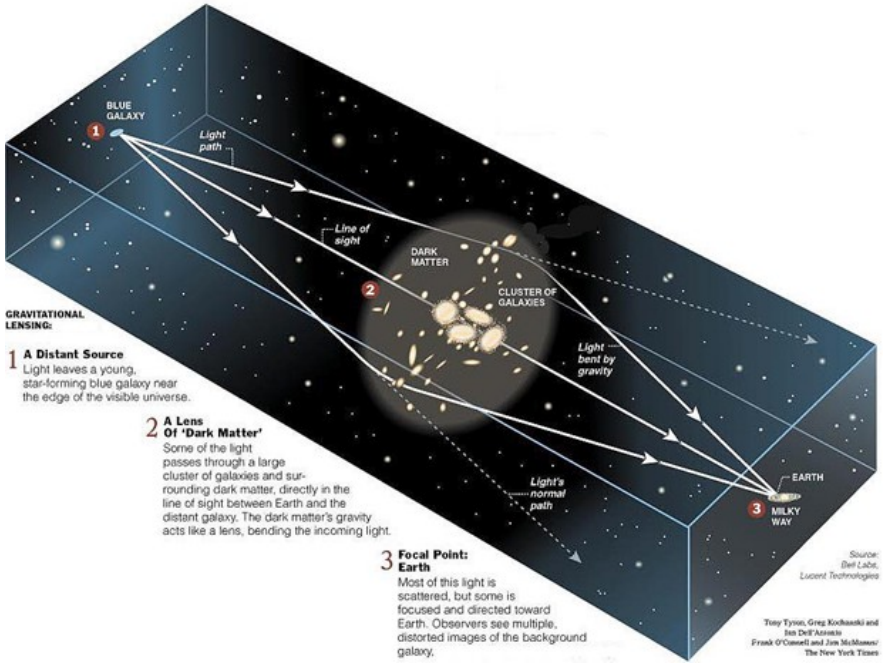


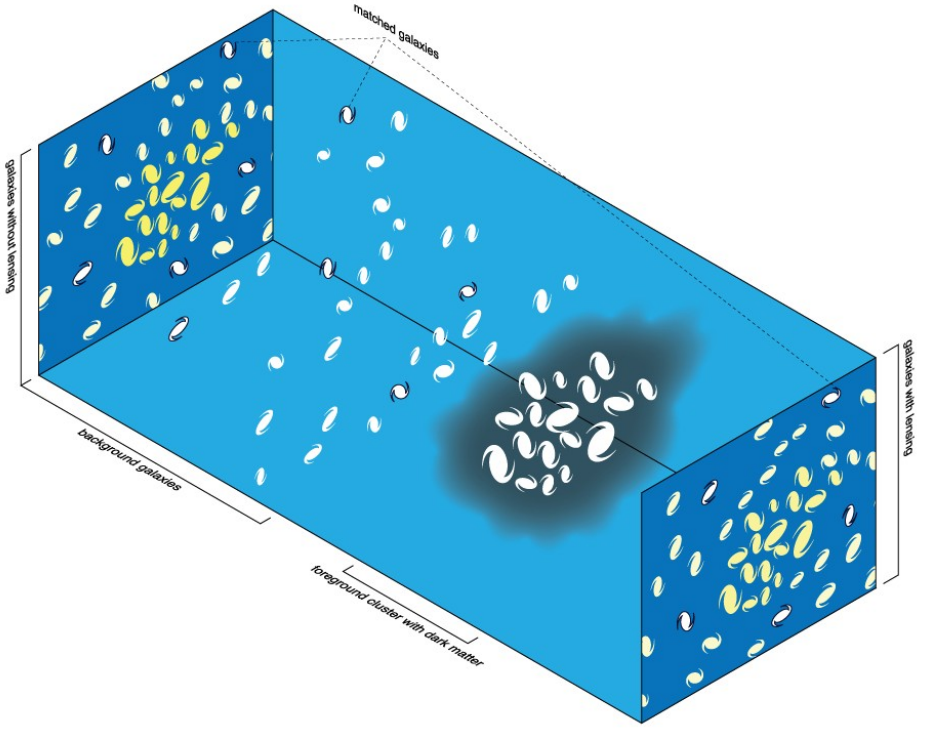
e world's largest radio telescope

What BAOs can tell us from distribution of galaxies

- Acoustic scale is physically calibrated ruler
- Can compare sound horizon today with CMB version, measure how much universe has expanded.
- Can measure angular diameter distance with a precision of 1%
- Measure cosmic expansion rate H(z) with 1-2% precision.
- Tests theories of dark energy and origin of cosmic acceleration.

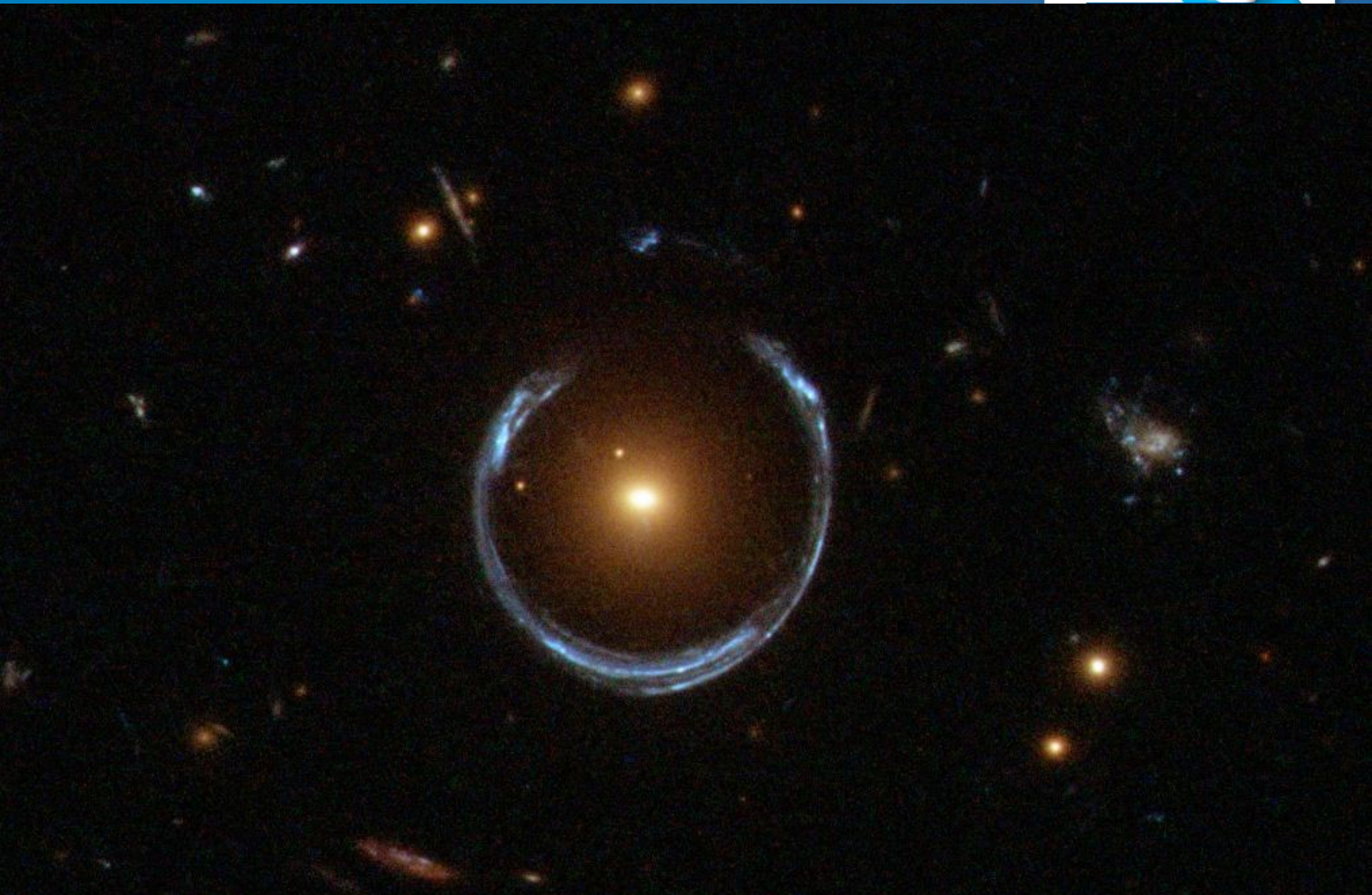
Cosmology with SKA1: Weak Gravitational Lensing



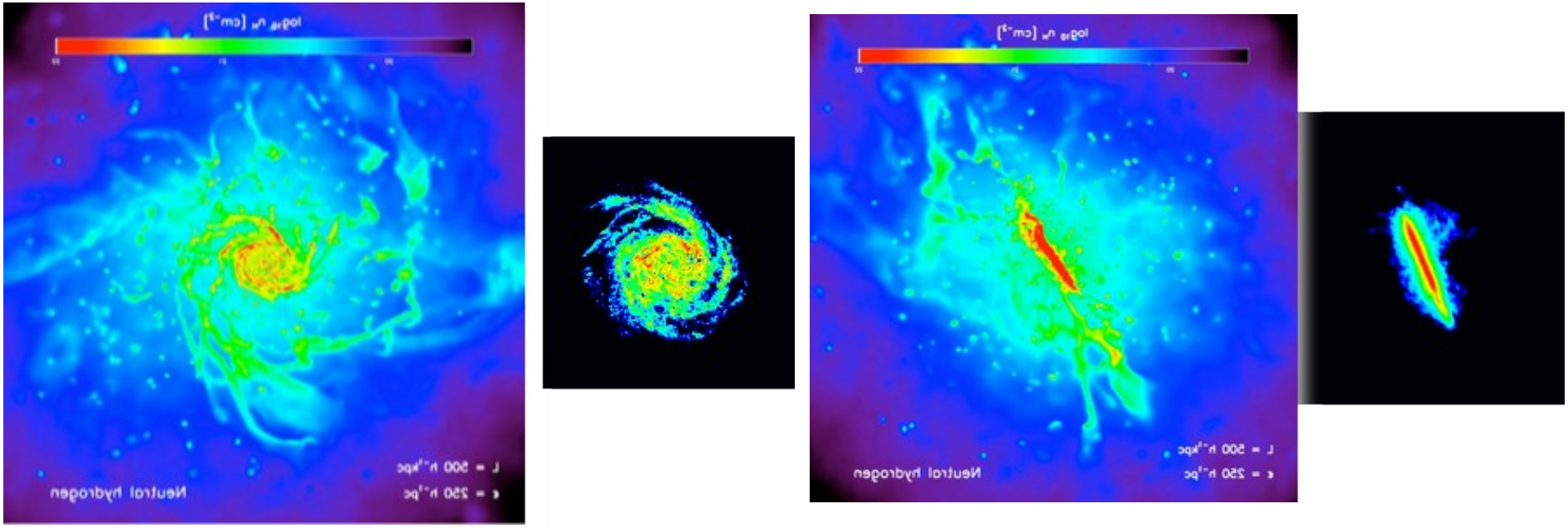


- Constraining the Dark Energy Equation of State with Weak Gravitational Lensing
- **Major enhancement in Dark Energy "Figure-of-Merit"**

Einstein ring – strong lensing



Galaxy Evolution with SKA1: Resolved HI Kinematics out to z ~ 0 – 0.8



(Simulations: Schaye et al. 2010, Images: Oosterloo 2014)

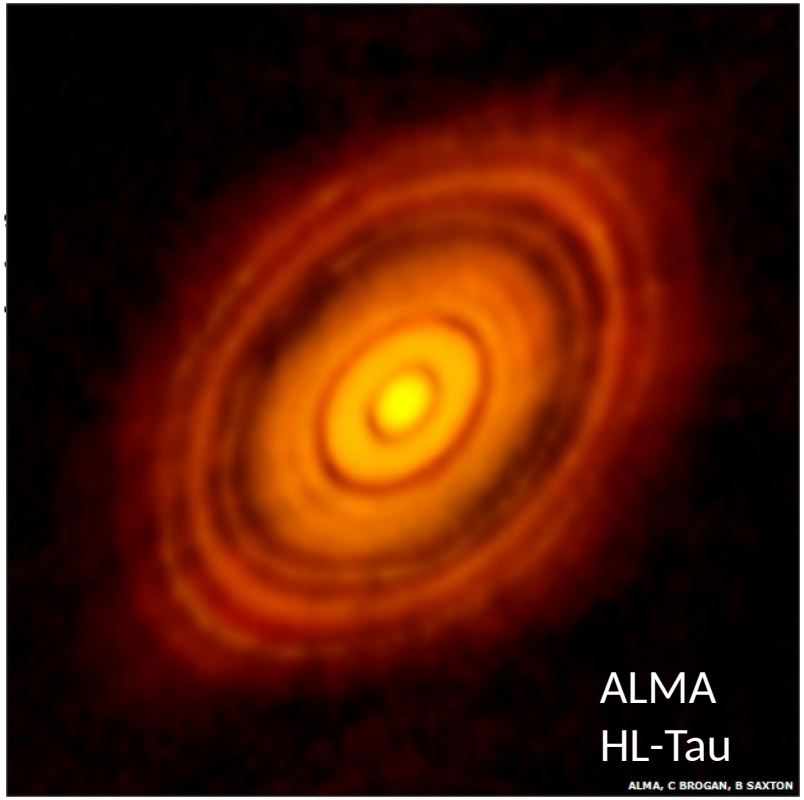
- Understanding galaxy assembly and the baryon cycle
  - Determine the impact of galaxy environments
  - Probe gas inflow and removal
  - Measure angular momentum build-up

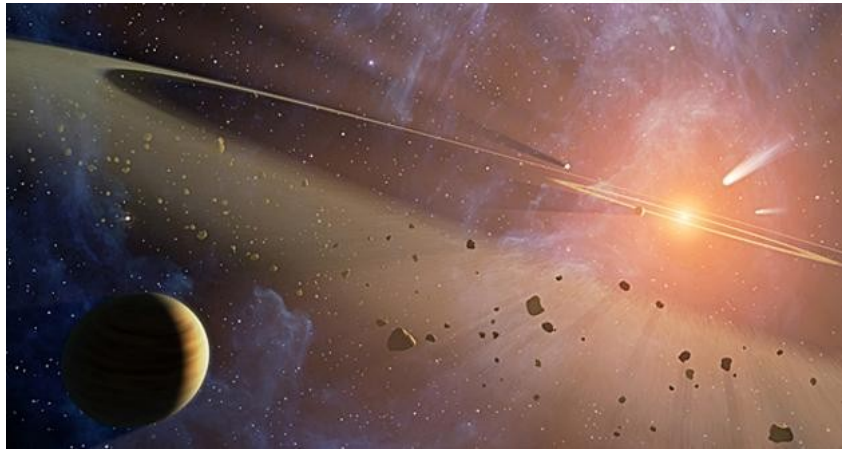
Origin of Cosmic Magnetism

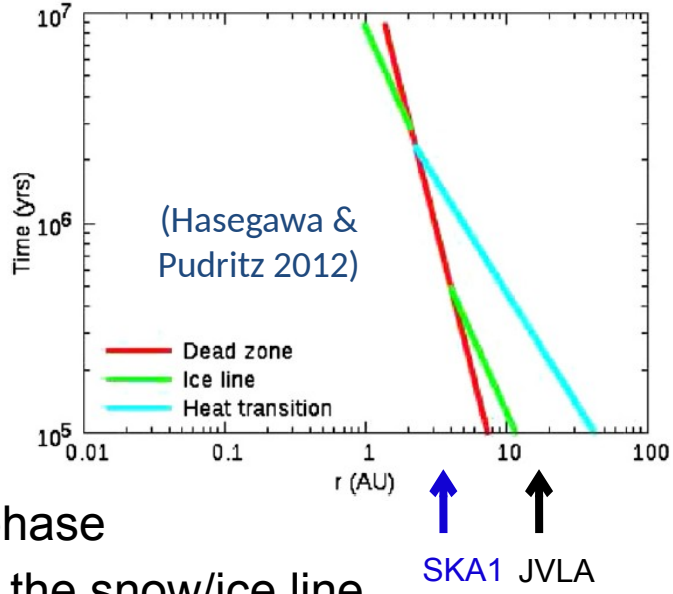
Radio observations have the unique ability to probe magnetic fields within and between galaxies.

Are magnetic fields primordial or are they a product of the physics of active galaxies?

The Cradle of Life: Understanding planet formation

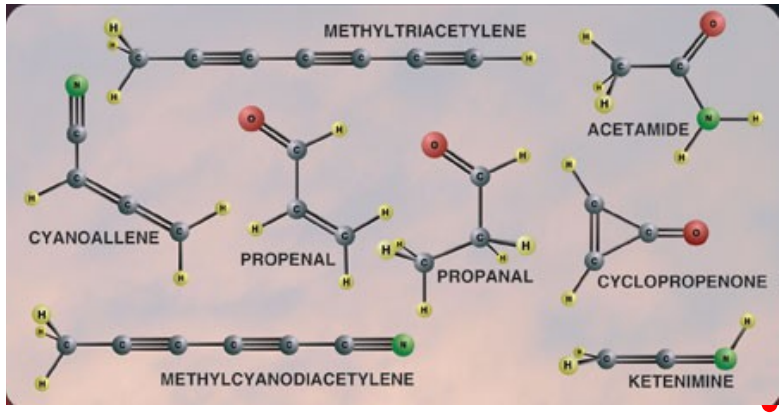






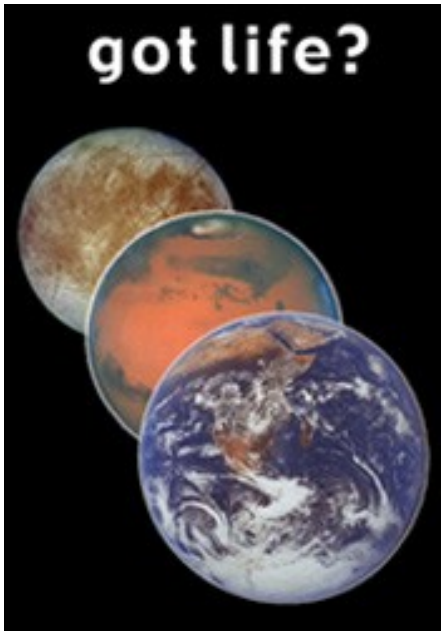
- Measuring grain growth through planetessimal phase
- Resolving proto-planetary disks at 100 pc inside the snow/ice line

Astrobiology

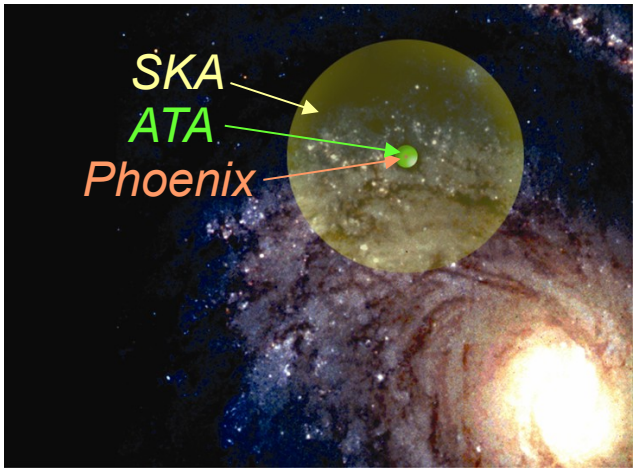


Detection of amino-acids and other complex carbon biomolecules

- have transitions at longer l

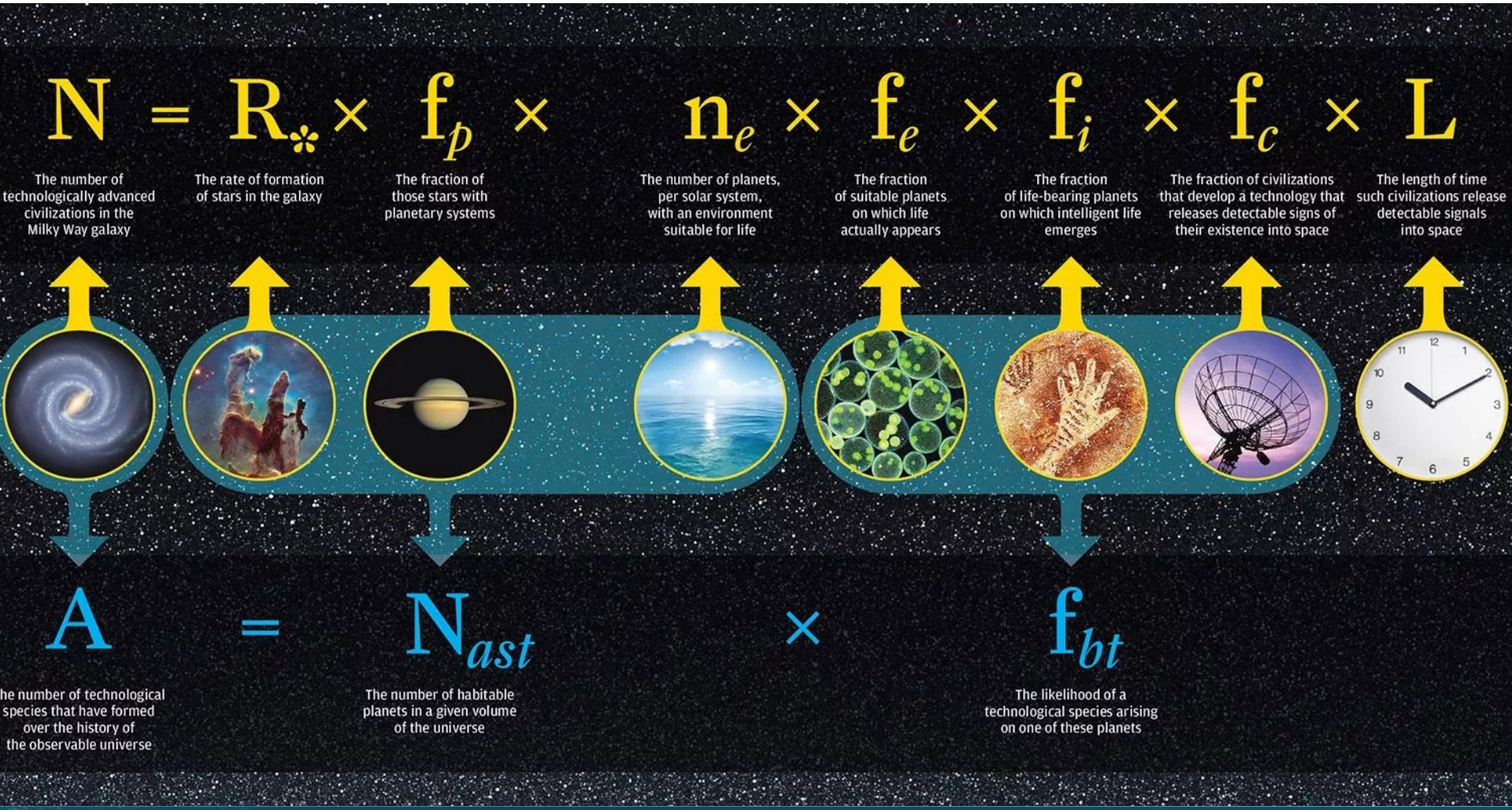


Detecting “leakage radiation” from extraterrestrial sources of radio emission.



Are we alone in the universe?

The Drake Equation



Breakthrough Listen

Exploration of the unknown
The Dynamic Radio Sky

- "Transient" sources
  - Locations of explosive or dynamic events in cosmos
    - Fast Radio Bursts (FRBs)
  - Probe fundamental physics and astrophysics

- Nature produces radio photons easily → detectable to great distances

- Radio transient sky is poorly explored

- The book of radio sky phenomena is still to be written … by the SKA !

Discovery is capricious but can be planned…

→ explore new regions of “parameter space”: enabled by technical innovations

High sensitivity always a route to success

While large radio telescopes of their day dominate the list of discoveries but are almost never known for what they were designed !!


SKA
SQUARE KILOMETRE ARRAY

SKA science will cover…

Fundamental "Stuff"

- Gravity
- Magnetism
- Dark Matter
- Dark Energy

Origins of Structures

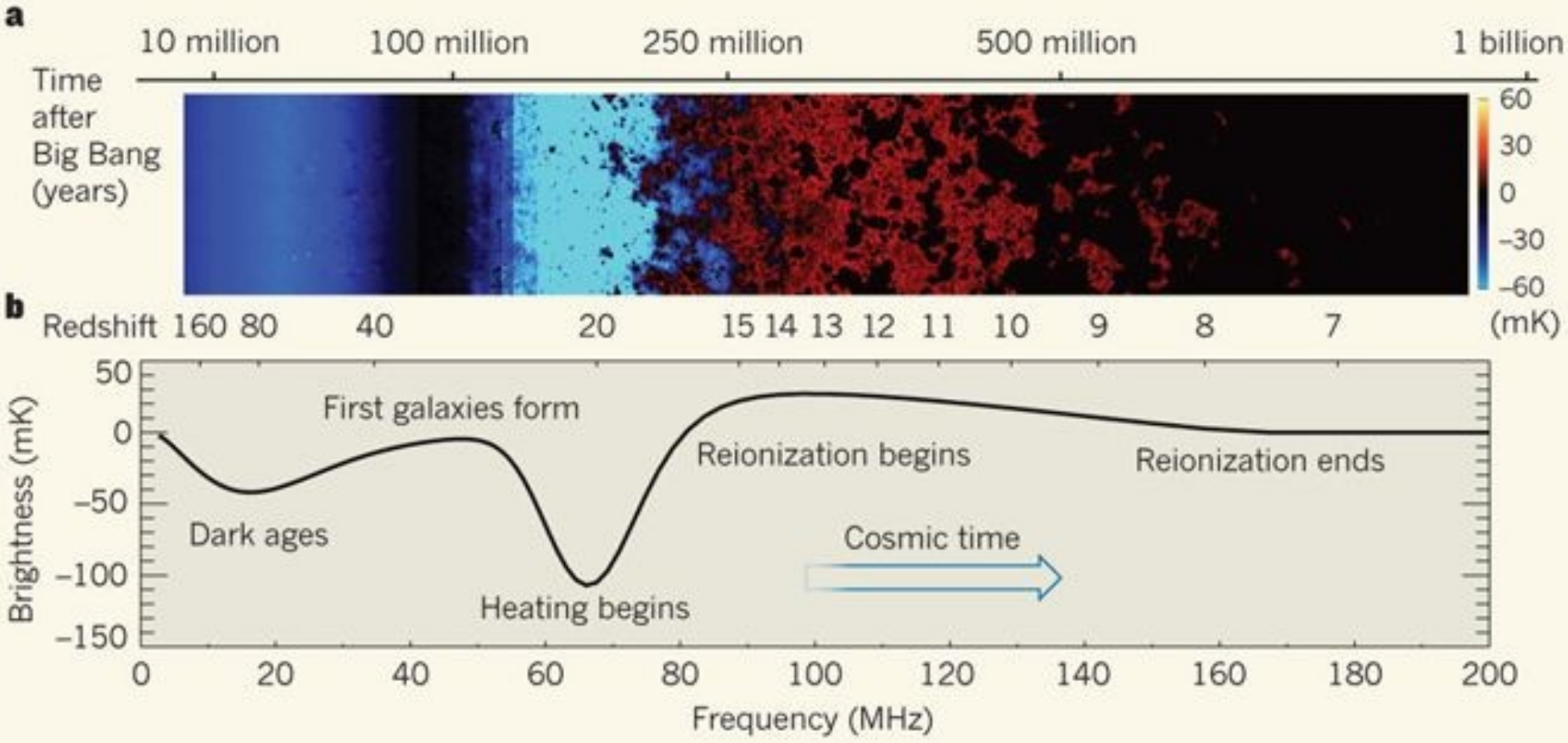
- The Universe
- Galaxies
- Stars, Planets,
- Life

What sort of studies?

- Different Wavelengths
- Time variations
- Polarization
- Greater Sensitivity
- Larger Field of View
- Higher Angular Resolution
- Greater survey speed

Are we alone in the Universe?

Cosmic origins
Physics behind HI temperature/z relation



"Hydrogen was not ionized abruptly" Jonathan Pritchard& Abraham Loeb
Nature **Vol.468**, pages772–773 (December 2010)