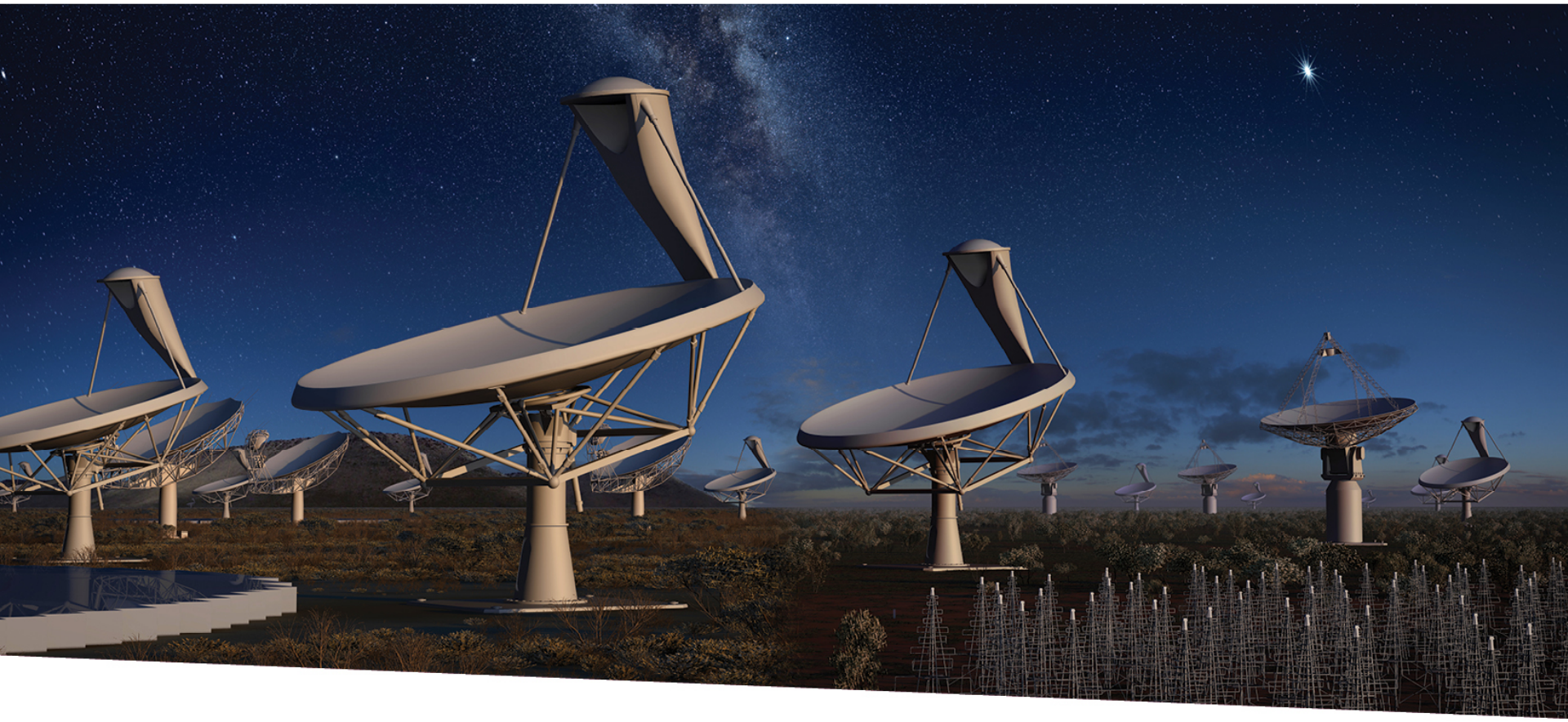
SKA Science



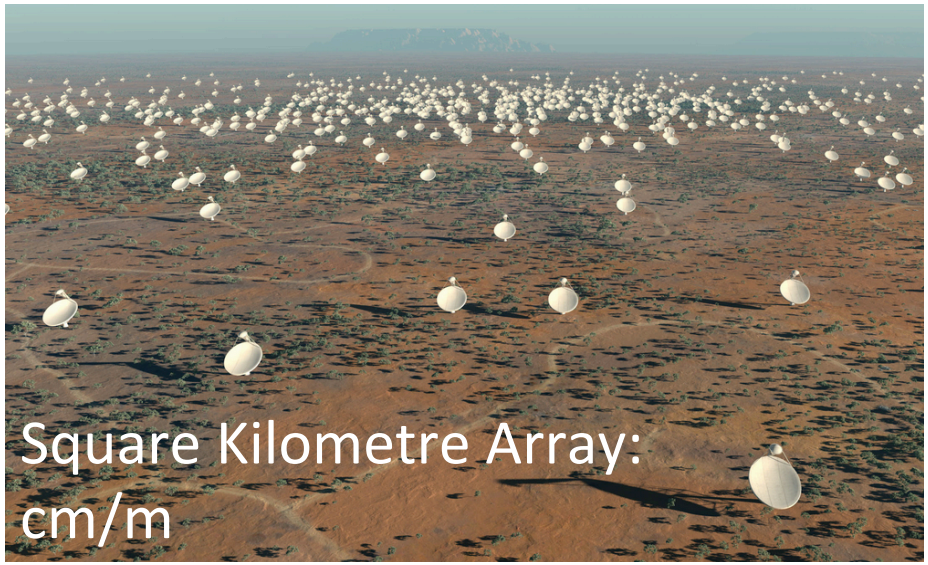
SQUARE KILOMETRE ARRAY

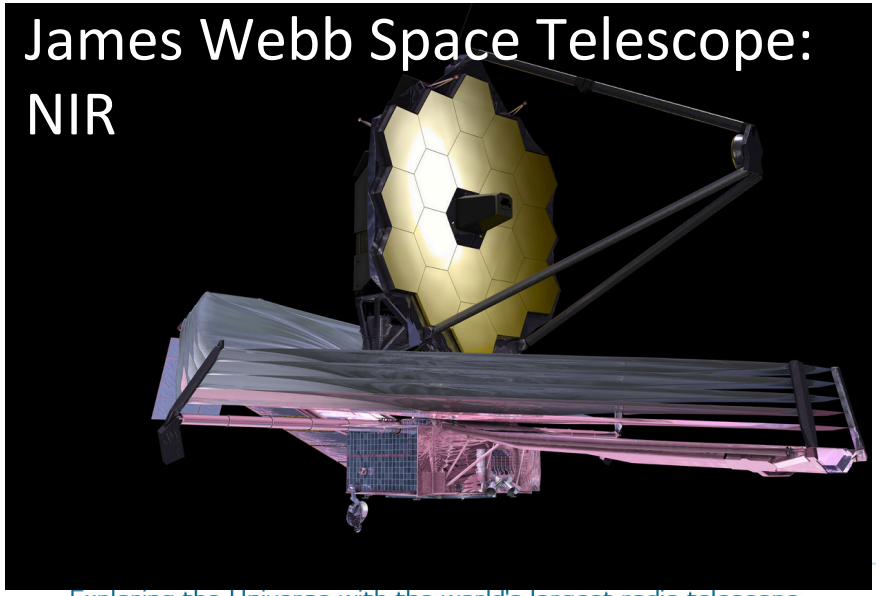
Exploring the Universe with the world's largest radio telescope

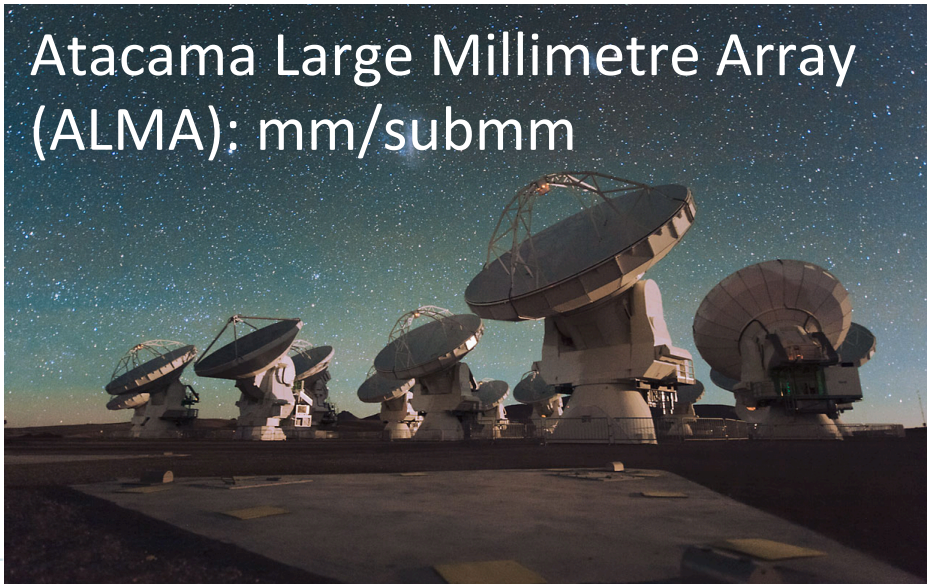
Robert Braun, Science Director

18 May 2016

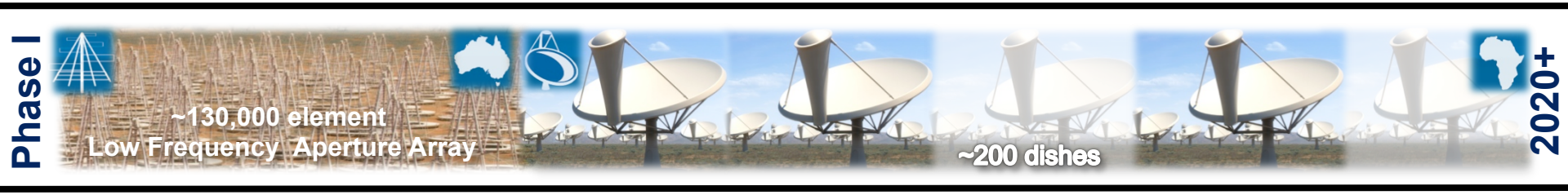
Great Observatories for the coming decades

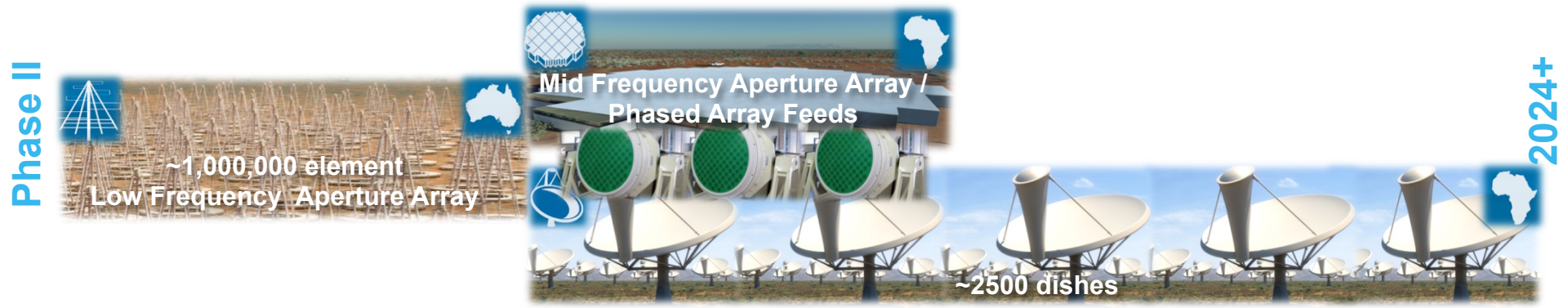




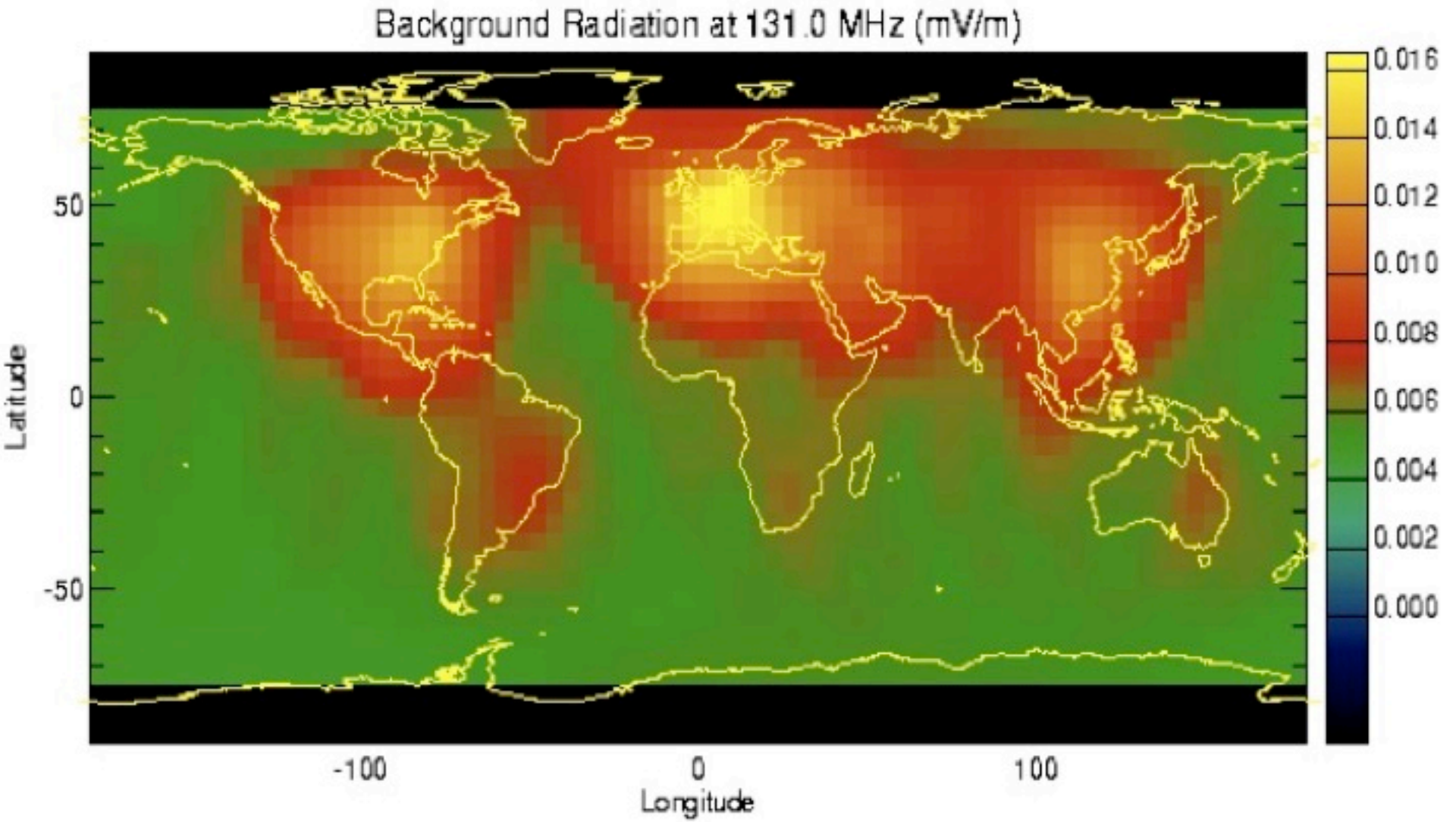


What is the SKA?





How did we choose the sites?



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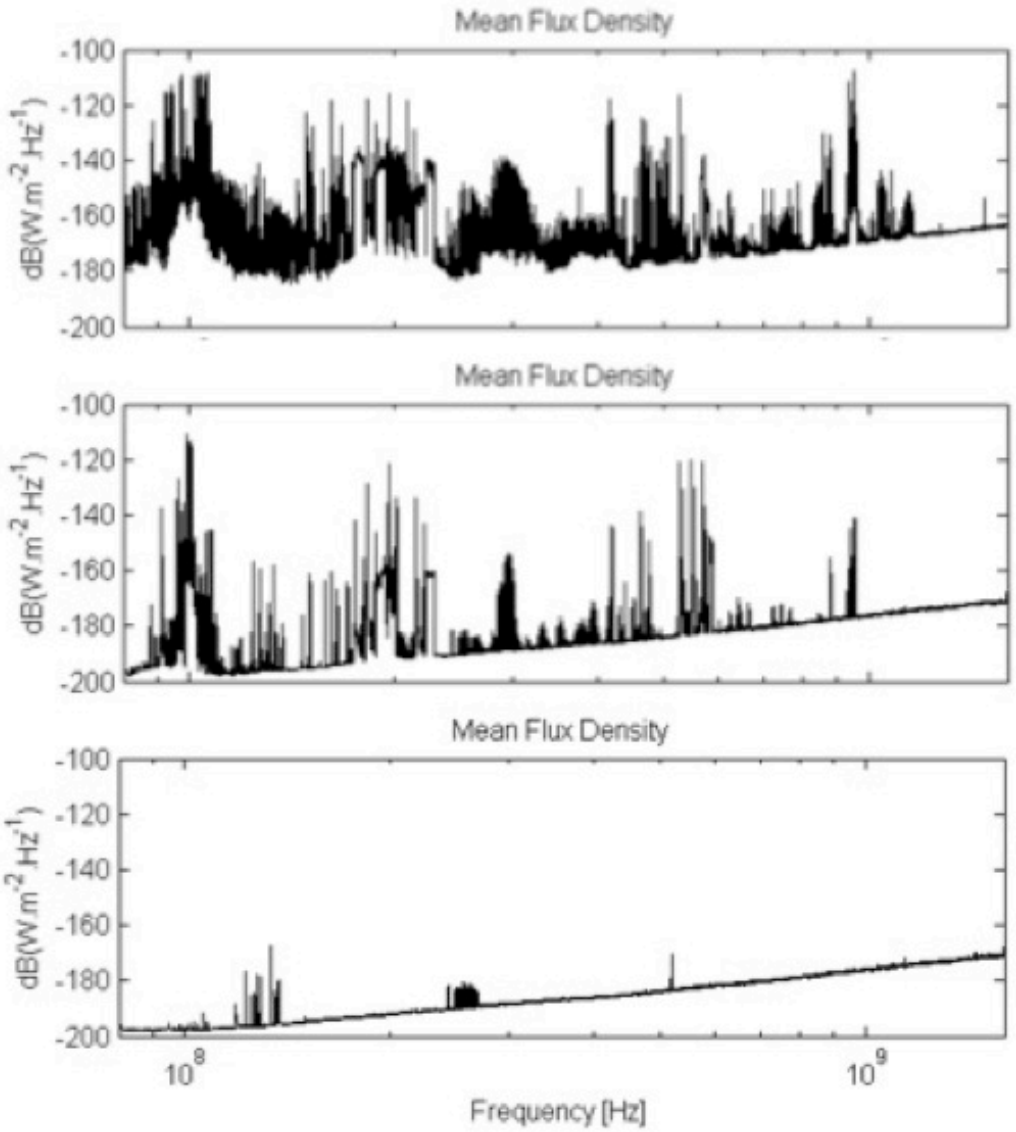
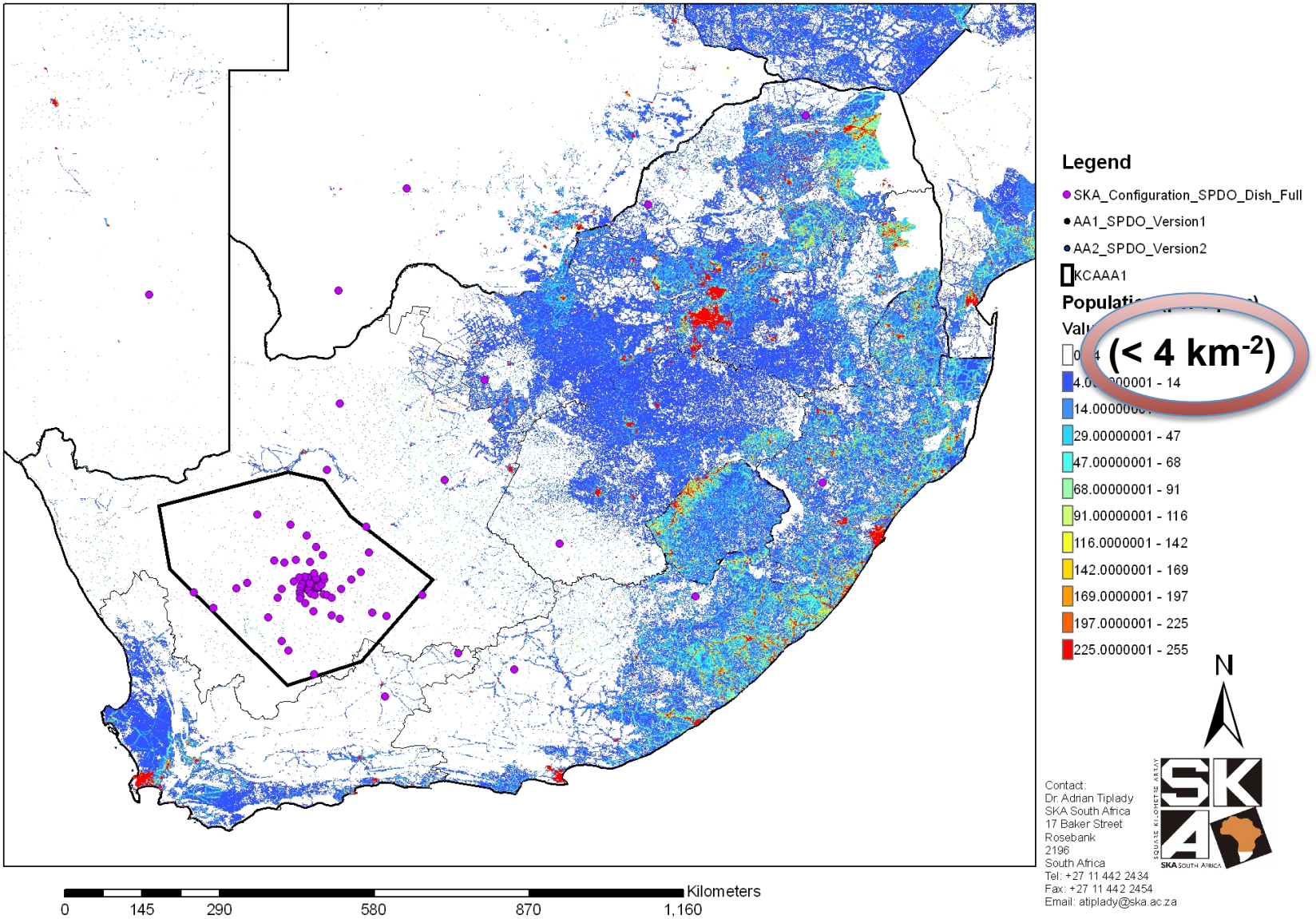


Sydney:
population 4 million

Narrabri:
population 4000

Mileura:
population 4

How did we choose the sites?

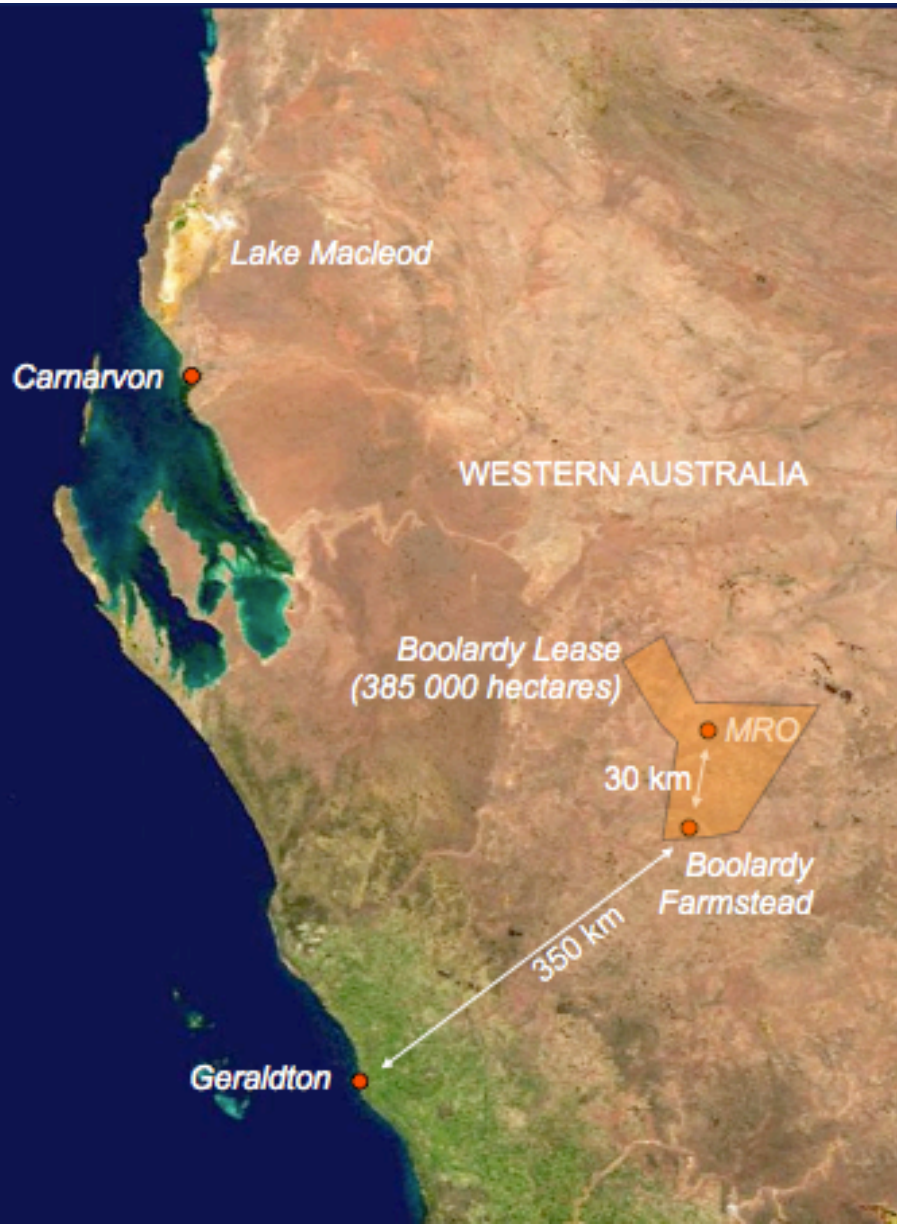


Contact:
Dr. Adrian Tiplady
SKA South Africa
17 Baker Street
Rosebank
2196
South Africa
Tel: +27 11 442 2434
Fax: +27 11 442 2454
Email: atiplady@ska.ac.za

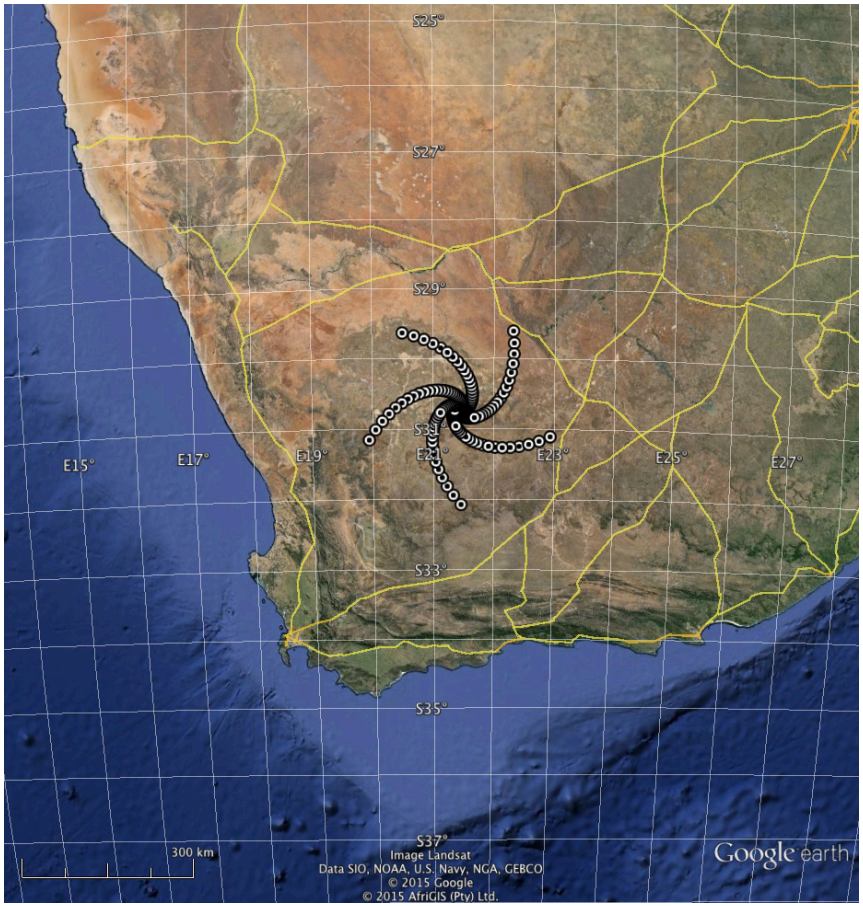
How did we choose the sites?

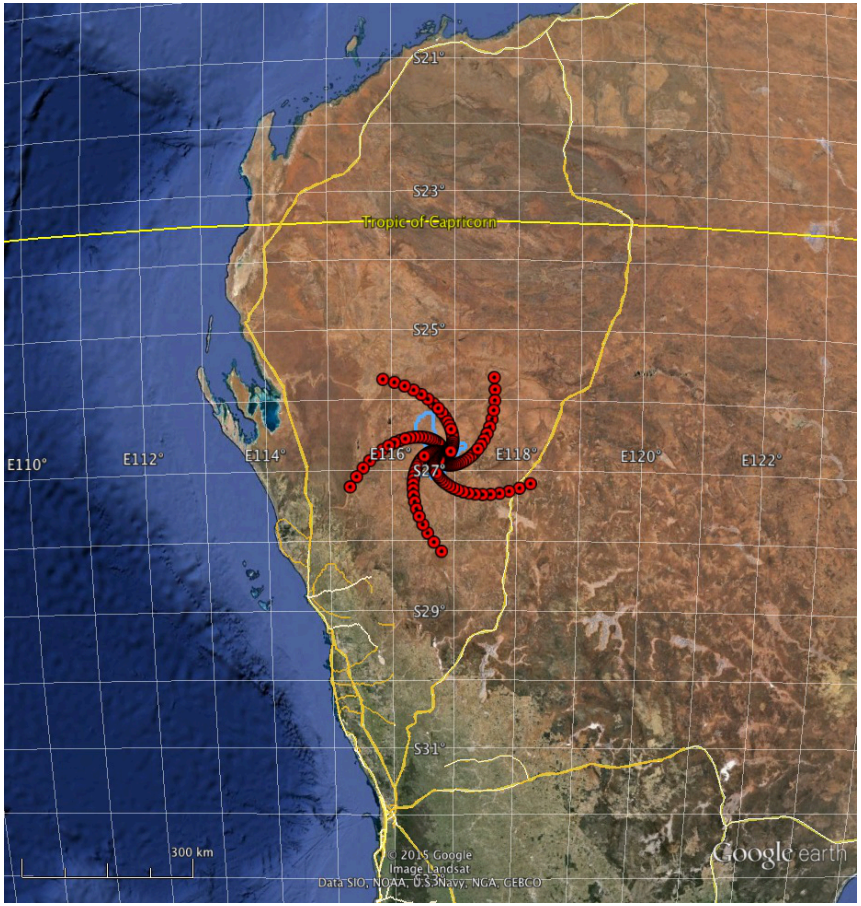
Shire of Murchison:

- 50,000 km²
- 0 gazetted towns
- 29 sheep/cattle stations
- 110 population (2×10^{-3} km^{-2})



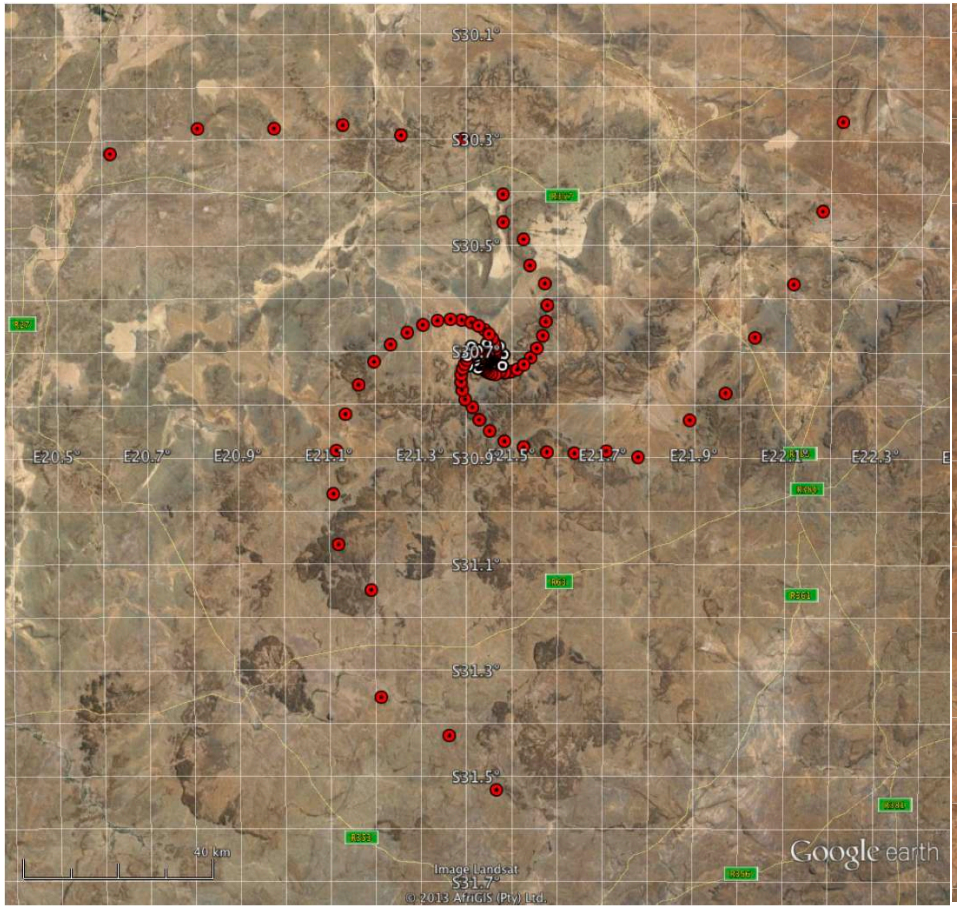
SKA2 Configurations

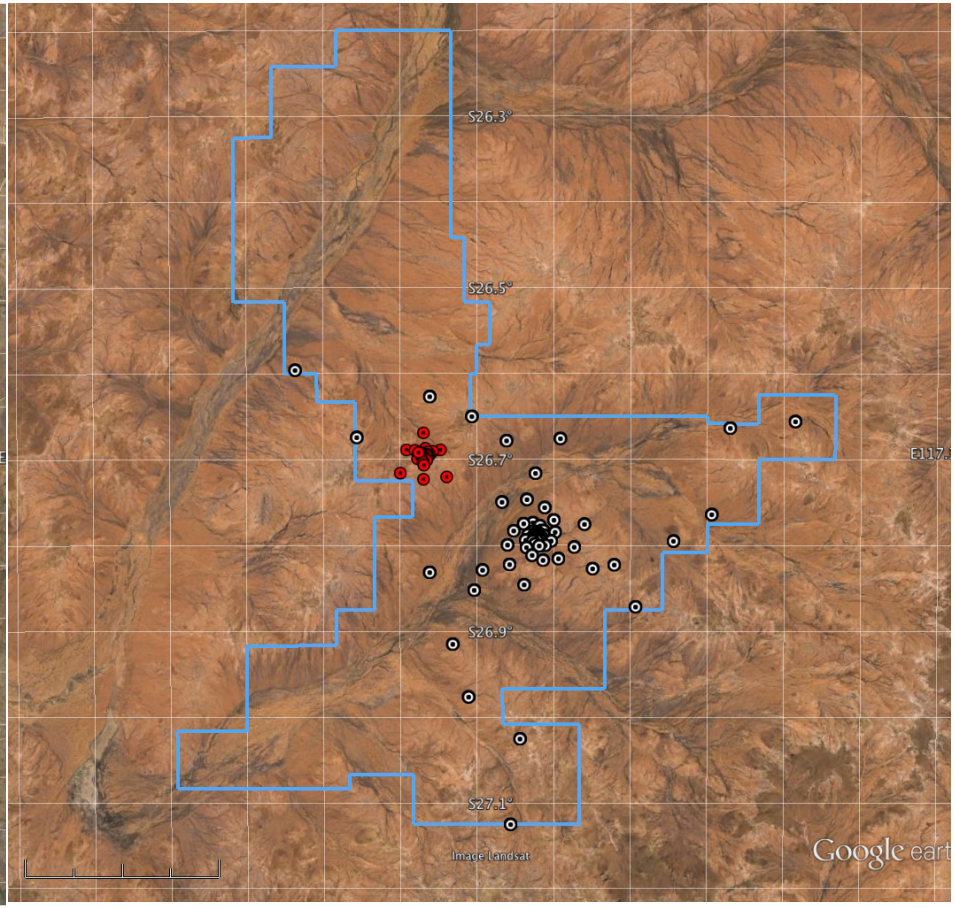




- SKA2–Dish, –LOW: B_{max} ≈ 300 km “core”, ≈3000+ km remote

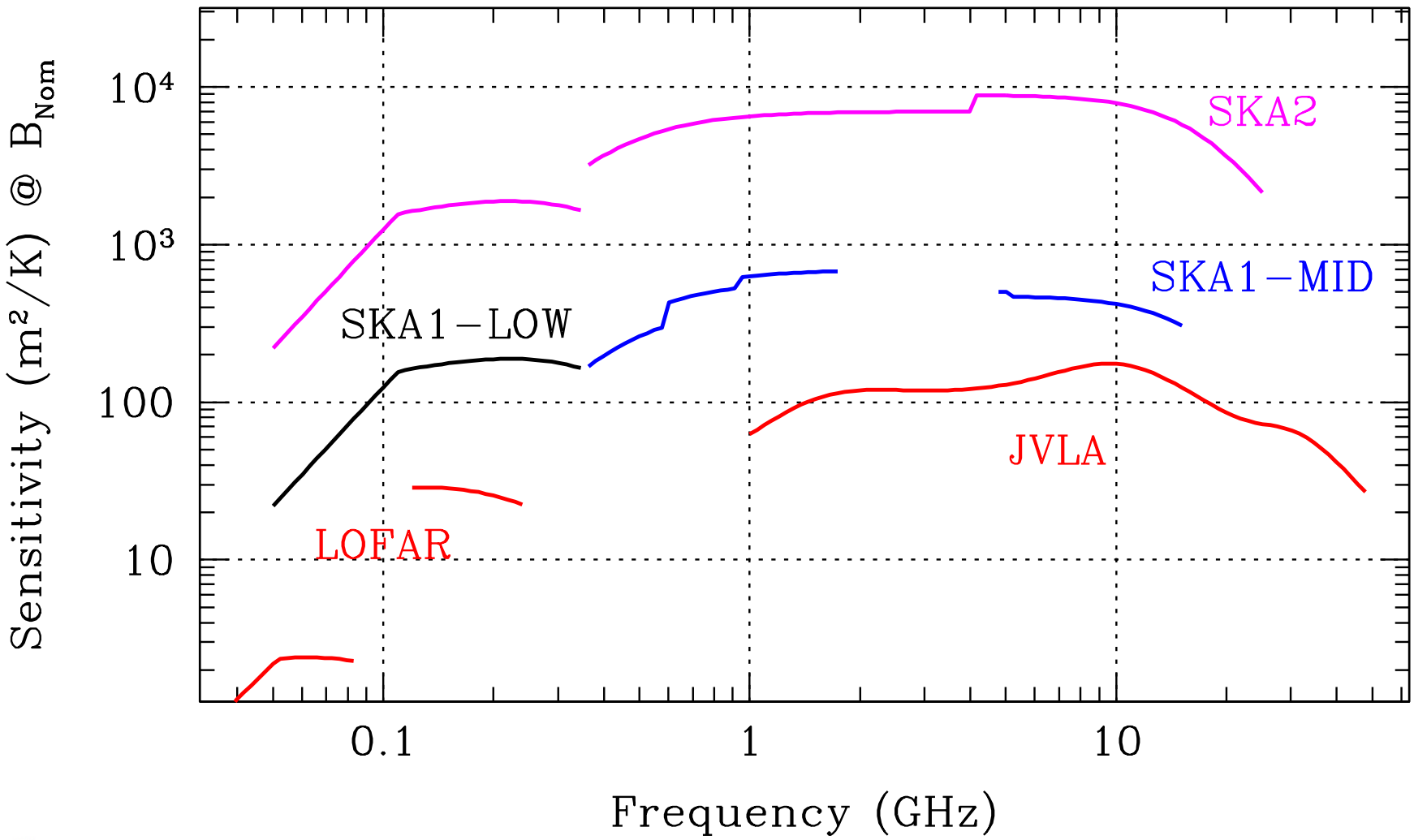
SKA1 Configurations



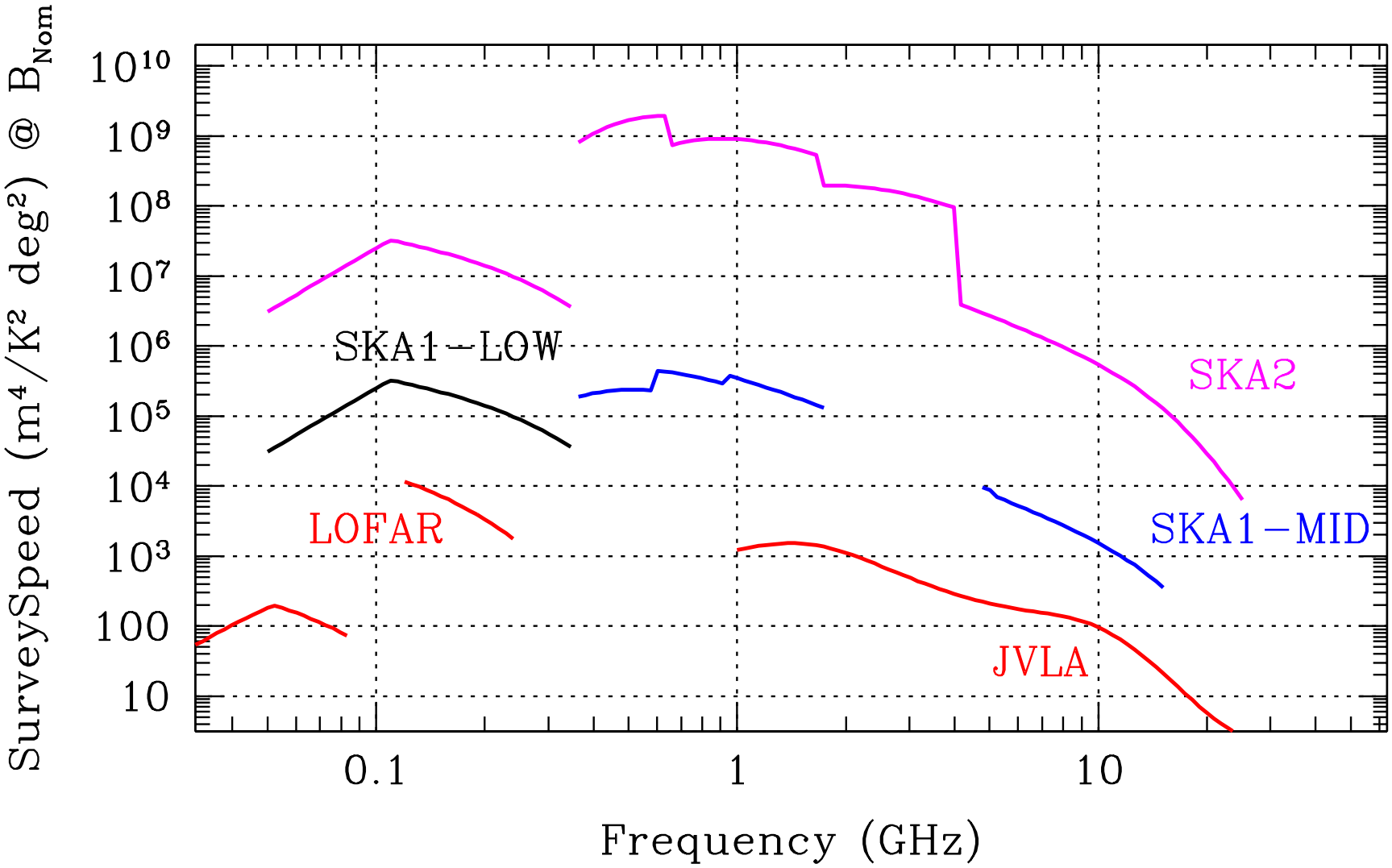


- SKA1–MID, –LOW: B_{Max} = 156, 65 km

Sensitivity Comparison



Survey Speed Comparison



Resolution Comparison

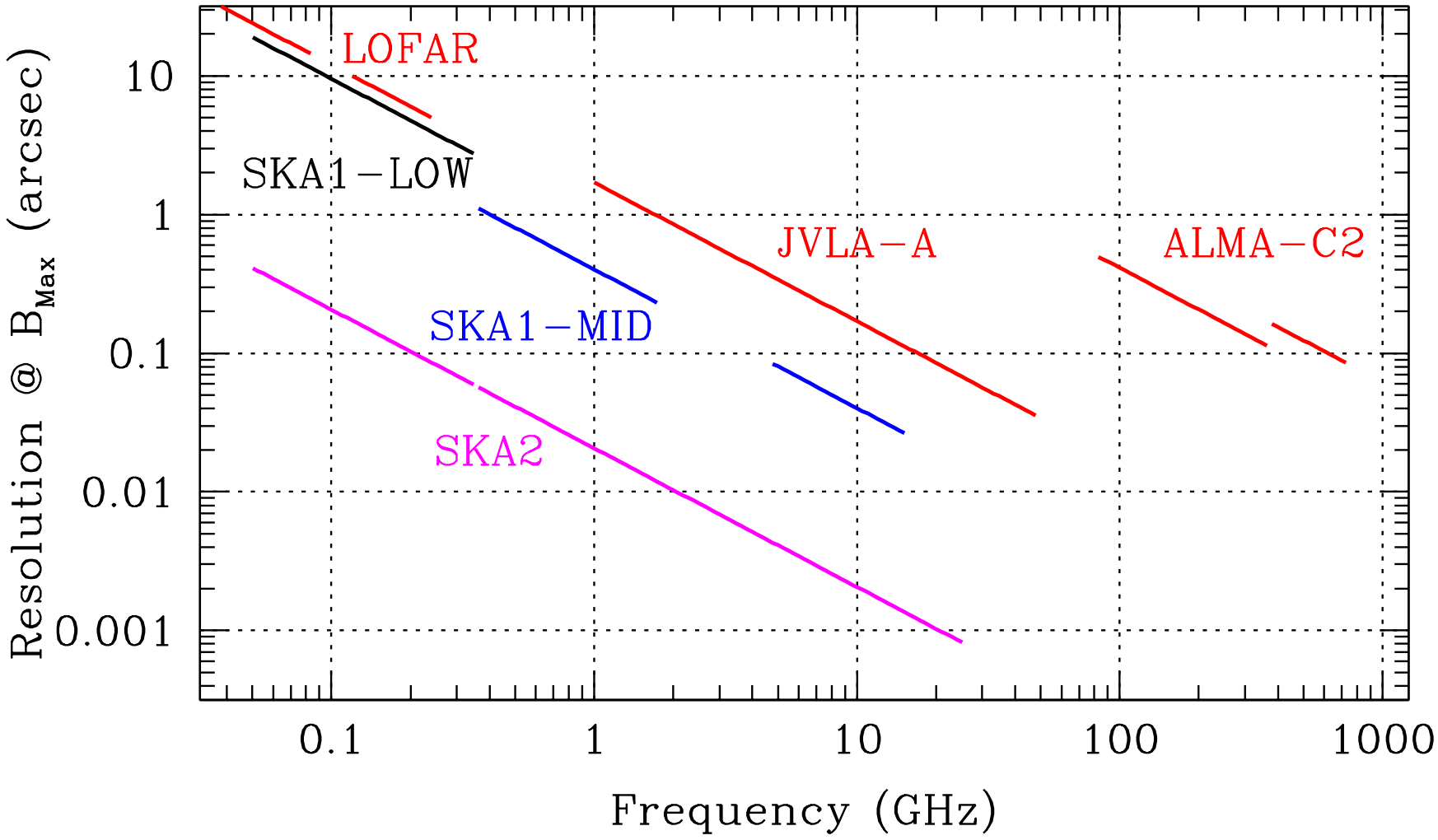


Image Quality Comparison

- Single SKA1 track equivalent to VLA A+B+C+D + **E+A⁺**
- "Structural" dynamic range of ~1000:1 rather than ~3:1 per track
- Beam quality ~100 times better than VLA

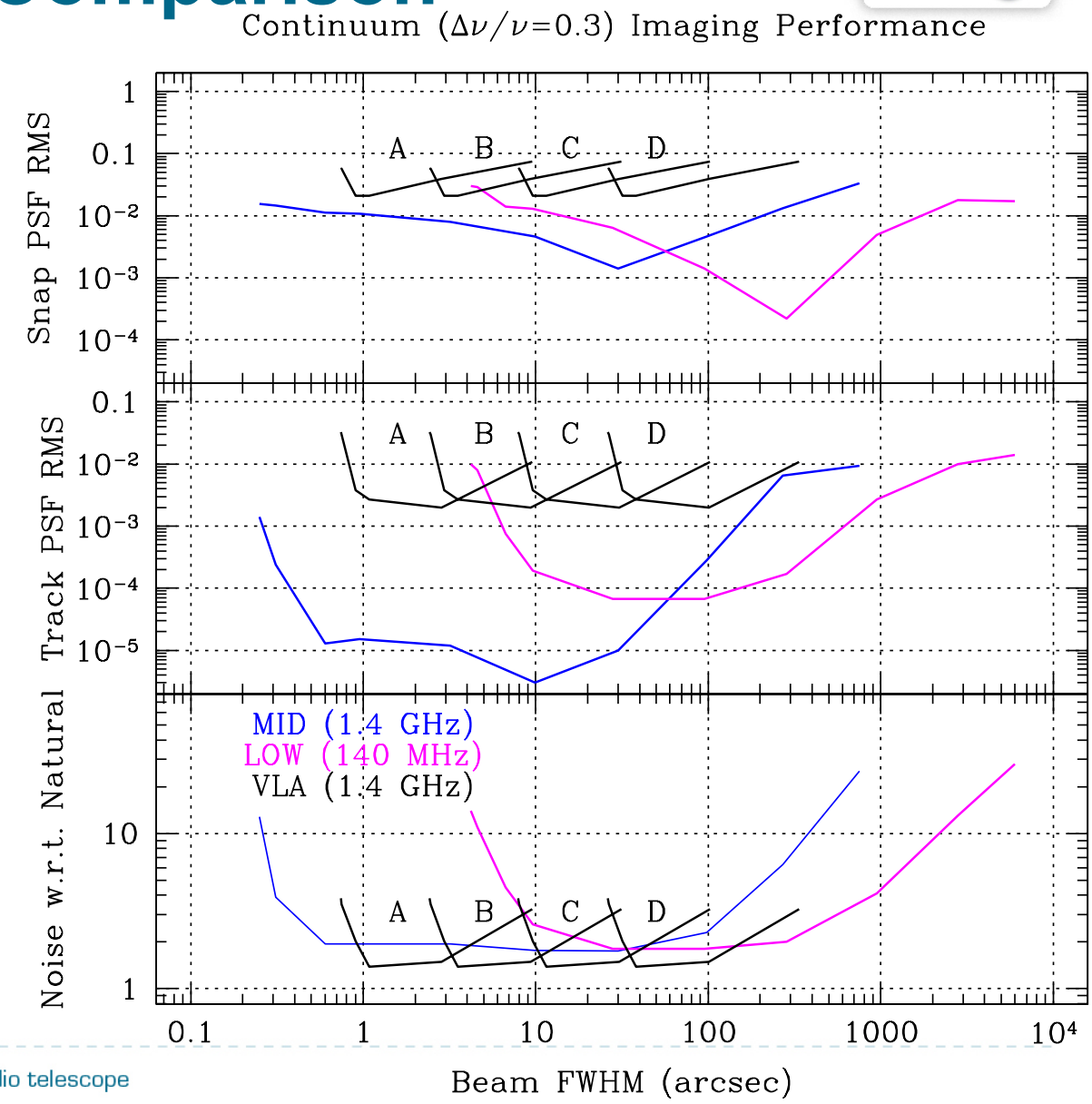
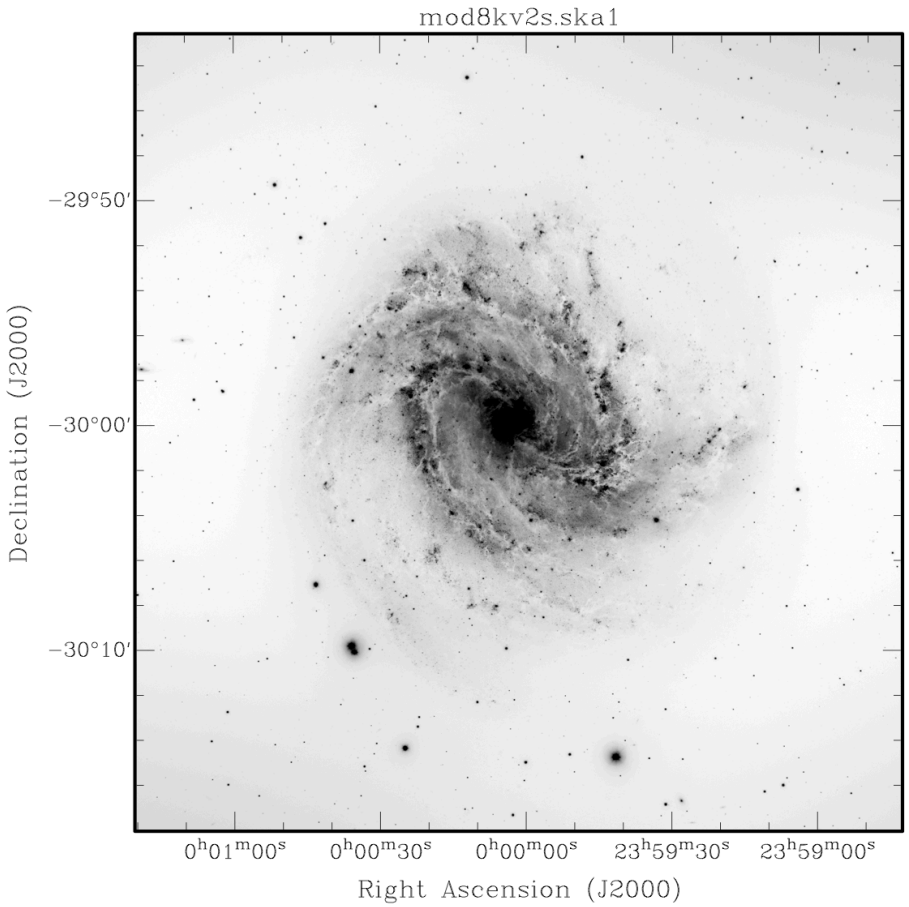
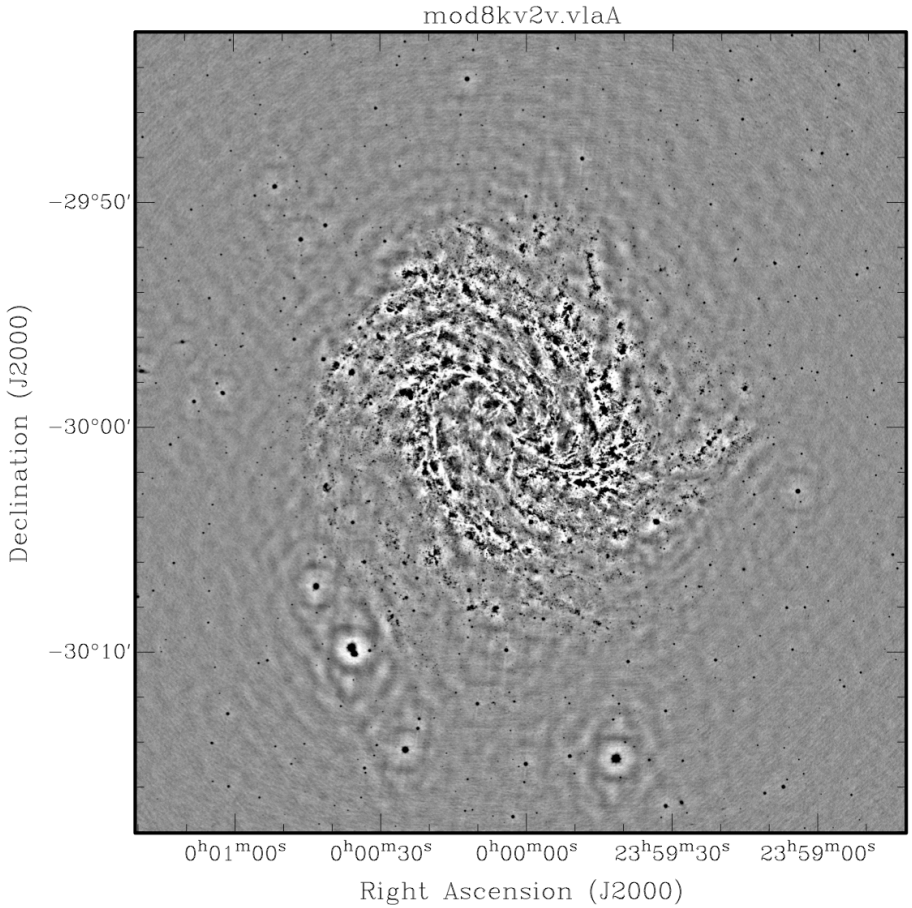


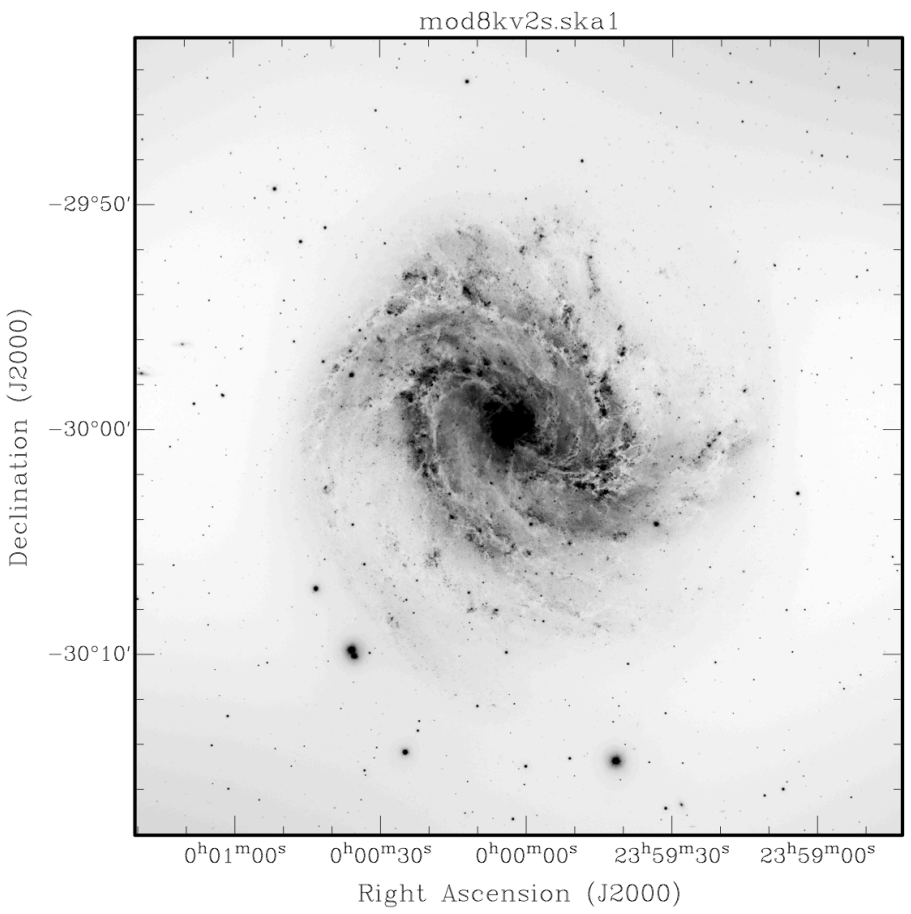
Image Quality Comparison

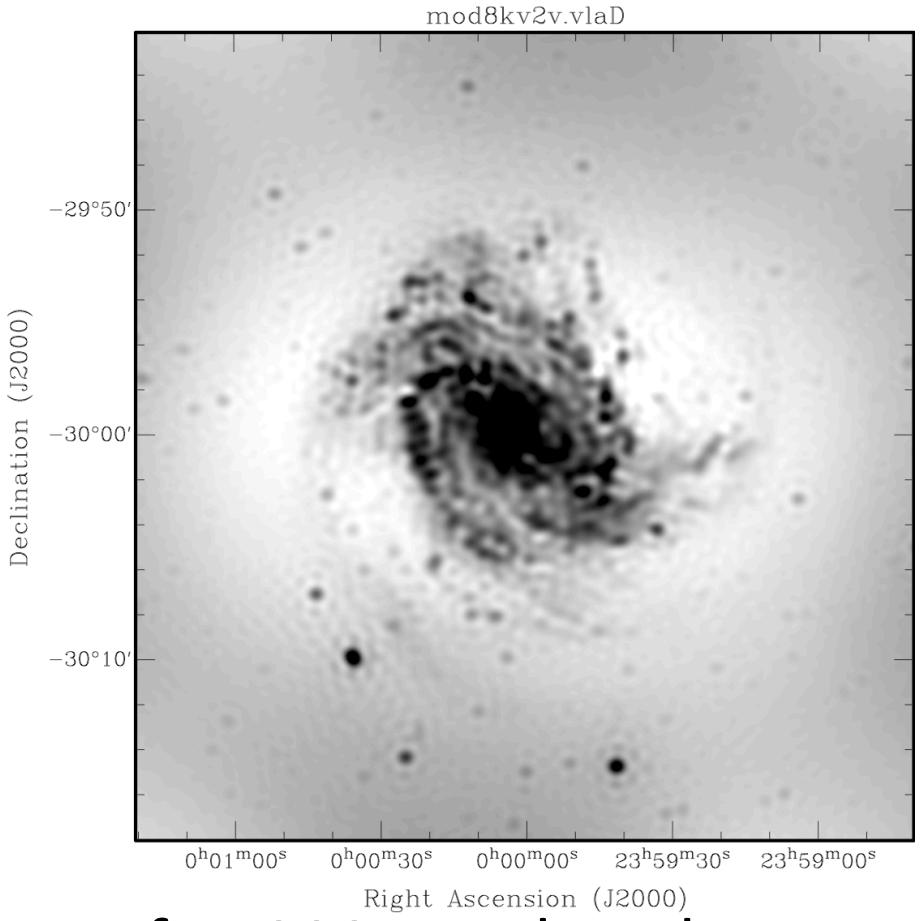




- "Structural" dynamic range of ~1000:1 rather than ~3:1 per VLA track (eg. SKA1-Mid vs. VLA A-config.)

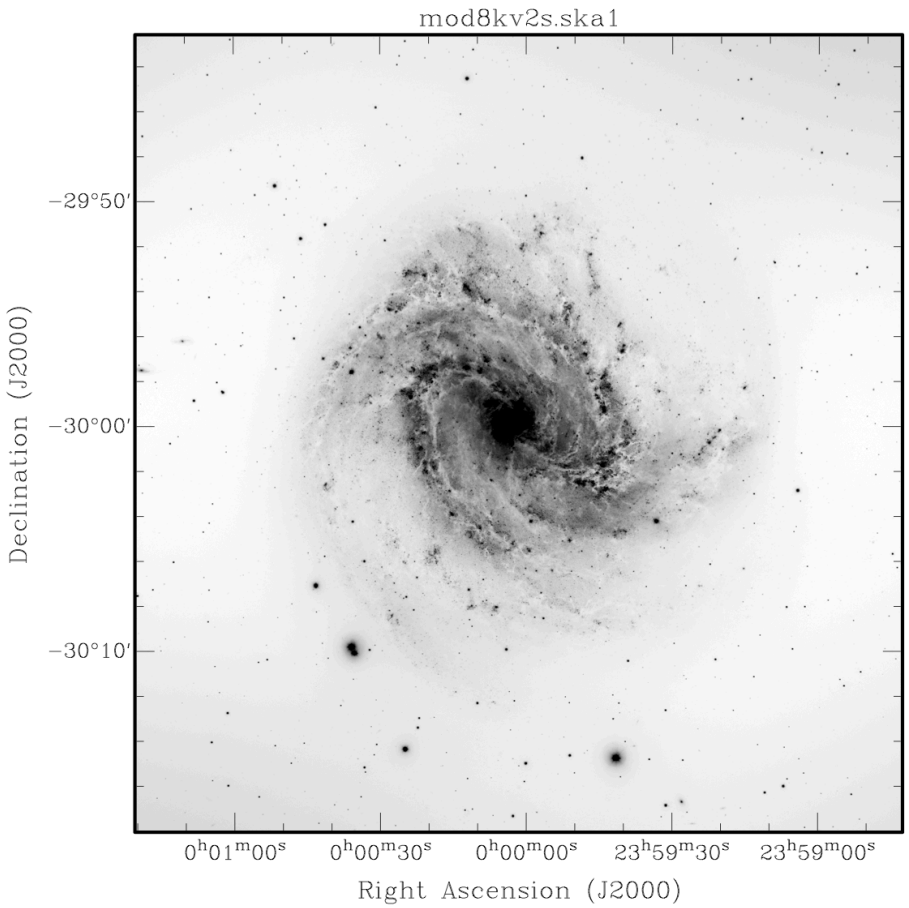
Image Quality Comparison

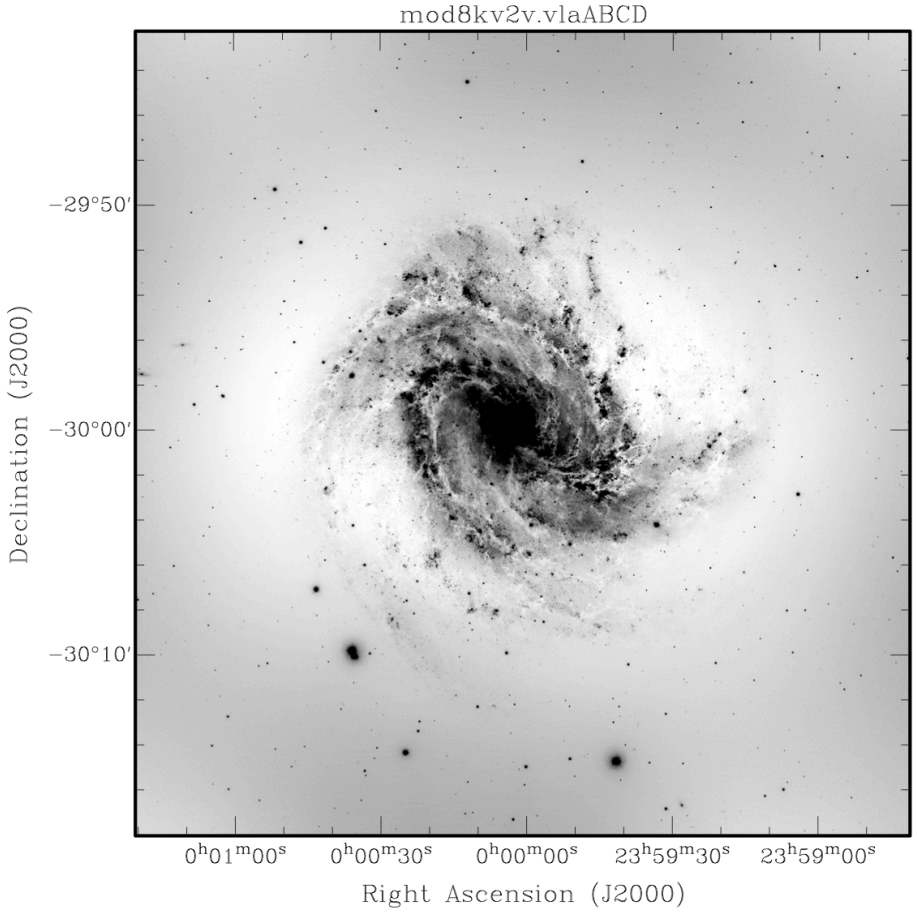




- "Structural" dynamic range of ~1000:1 rather than ~3:1 per VLA track (eg. SKA1-Mid vs. VLA D-config.)

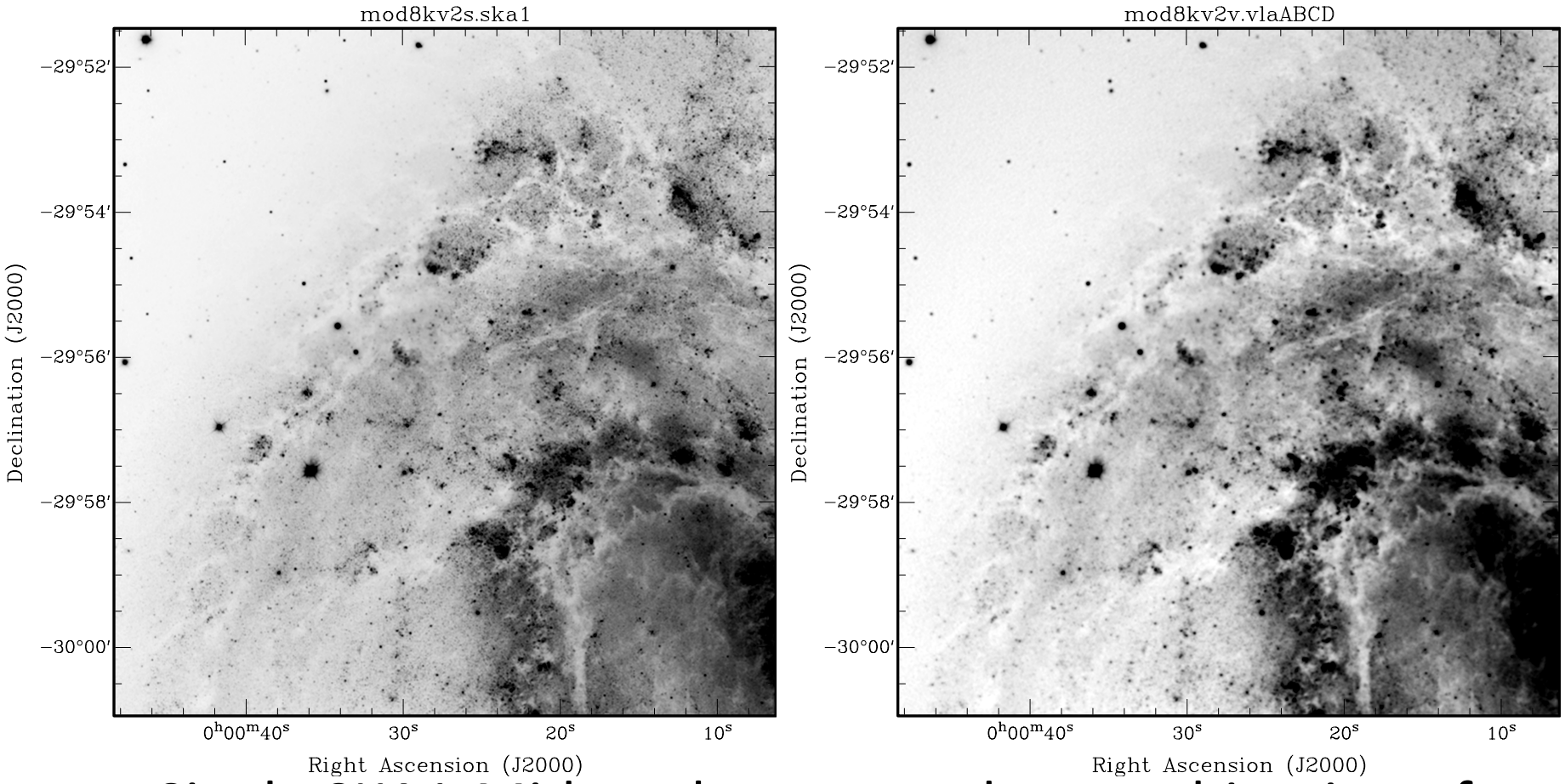
Image Quality Comparison





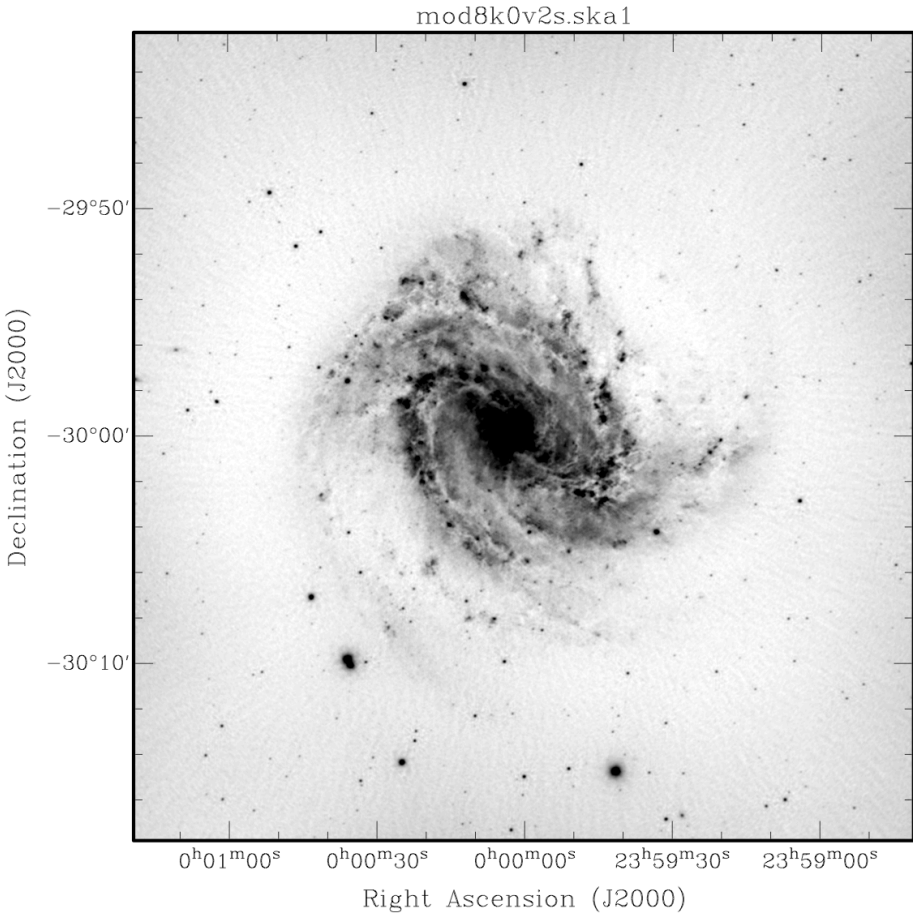
- Single SKA1-Mid track compared to combination of tracks in each of VLA A+B+C+D

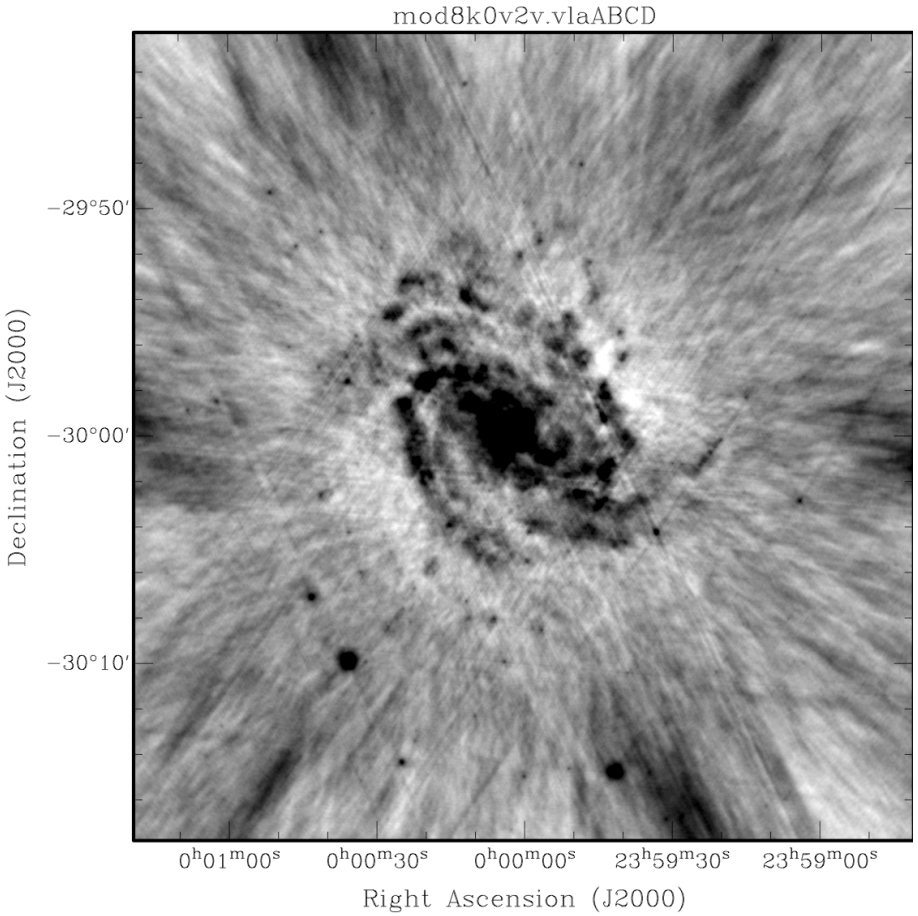
Image Quality Comparison



- Single SKA1-Mid track compared to combination of tracks in each of VLA A+B+C+D

Image Quality Comparison





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

SKA Science

- SKA: will be one of the great physics machines of 21st Century and, when complete, one of the world's engineering marvels.
- Science goals:
  - Fundamental physics: Gravity, Dark Energy, Cosmic Magnetism
  - Astrophysics: Cosmic Dawn, First galaxies, galaxy assembly and evolution; proto-planetary discs, biomolecules, SETI + much more
  - The unknown: transients; +…????

Advancing Astrophysics

with the Square Kilometre Array

9-13 June 2014, Giardini Naxos, Italy

#skascicon14

2014 marks 10 years since the publication of the comprehensive **'Science with the Square Kilometre Array'** book and 15 years since the first such volume appeared in 1999. In that time numerous and unexpected advances have been made in the fields of astronomy and physics relevant to the capabilities of the Square Kilometre Array (SKA). This meeting will facilitate the publication of a new, updated science book, which will be relevant to the current astrophysical context.

Scientific Organising Committee

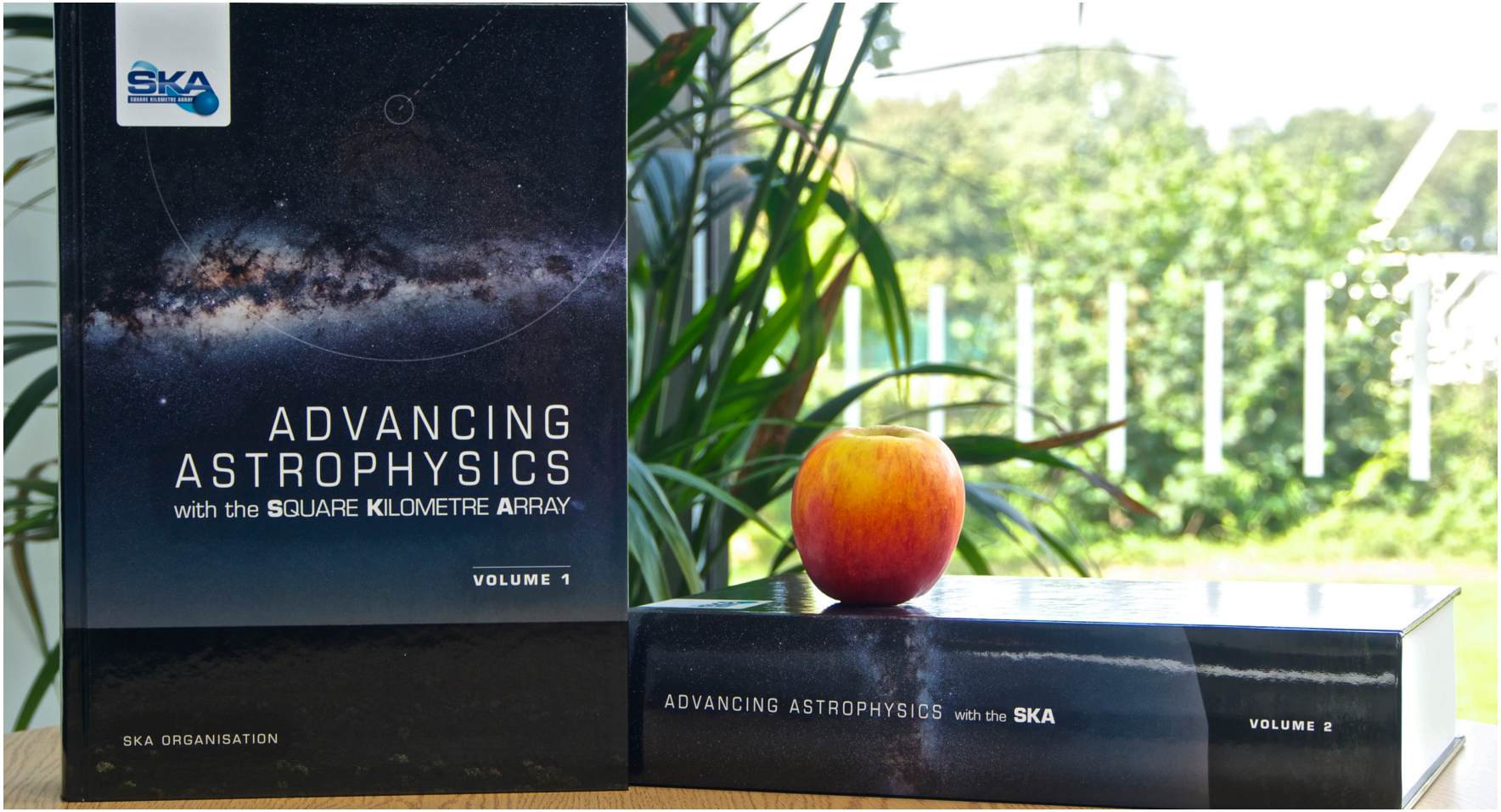
Robert Braun (SKAO) – co-Chair
Grazia Umana (INAF-OACt) – co-Chair
Tyler Bourke (SKAO)
Rob Fender (Oxford)
Federica Govoni (INAF–OA Cagliari)
Jimi Green (SKAO)
Melvin Hoare (Leeds)
Melanie Johnston-Hollitt (Victoria Univ. Wellington)
Leon Koopmans (Kapteyn Astronomical Institute)
Michael Kramer (MPIfR)
Roy Maartens (Univ. Western Cape)
Tom Oosterloo (ASTRON)
Isabella Prandoni (INAF–IRA)
Nicholas Seymour (CASS)
Ben Stappers (Manchester)
Lister Staveley-Smith (ICRAR)
Wen Wu Tian (NAOC)
Jeff Wagg (SKAO)

Enquiries: ska-june14@skatelescope.org
or visit: indico.skatelescope.org/event/AdvancingAstrophysics2014

SKA Science Book:

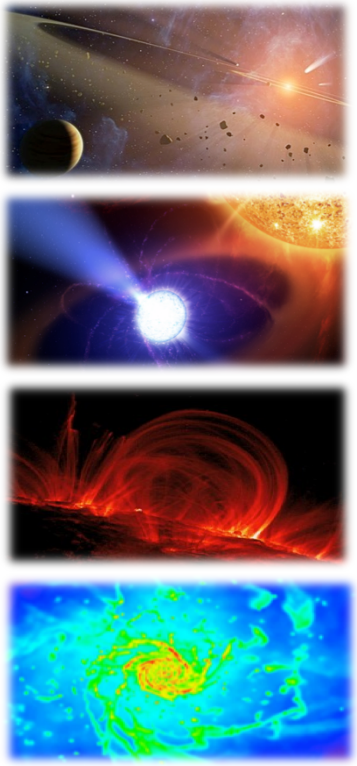
- Meeting Program based on advanced Chapter drafts
- 135 self-contained chapters with 1200 contributors
- Published electronically in PoS May 2015
- Printed Book ~2000 pages, in 2 volumes now out
  - Weighs in at 8.8 kg!

SKA Science Book 2015



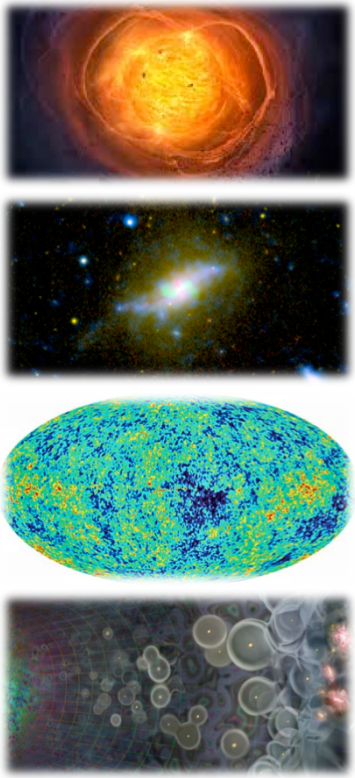
Headline Science with SKA1 and SKA2

	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.

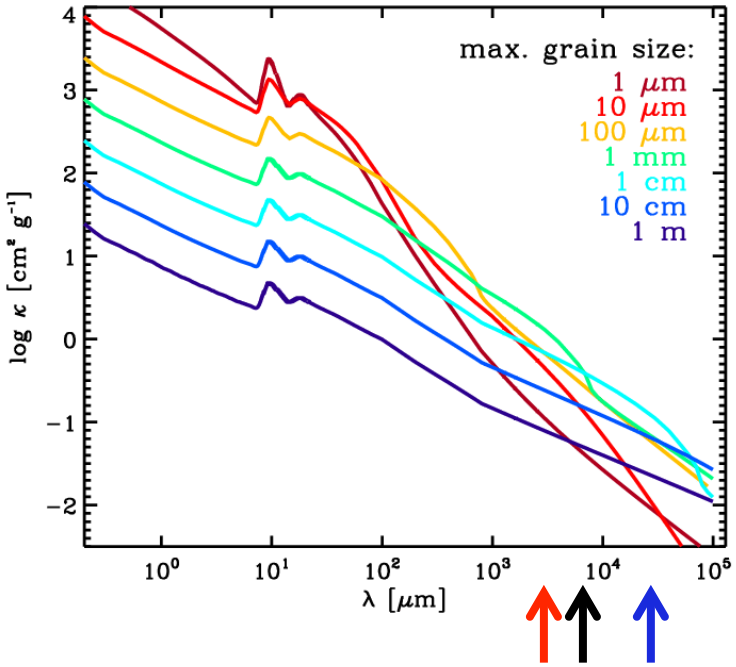


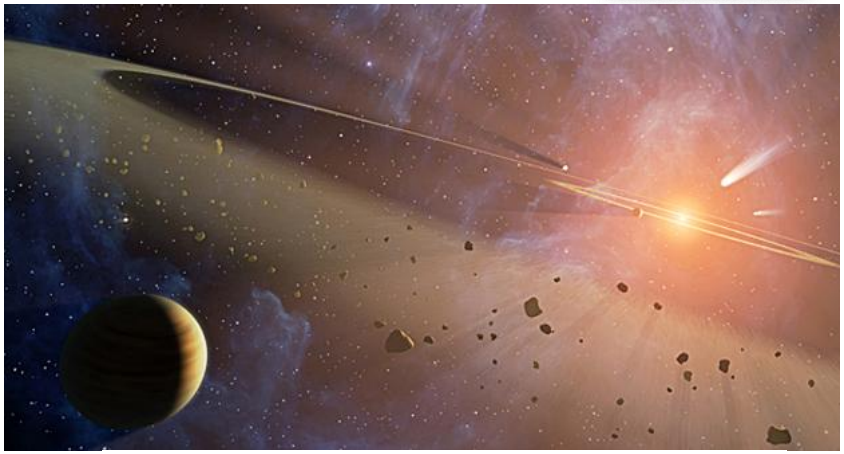
Headline Science with SKA1 and SKA2

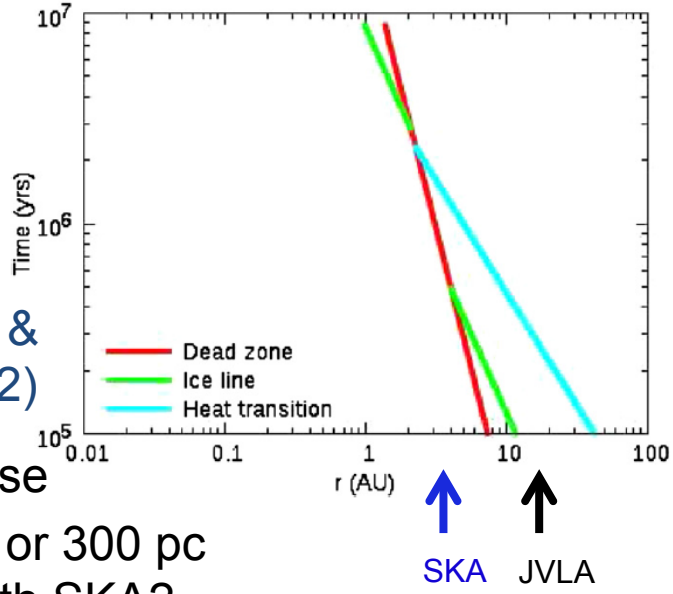
	SKA1	SKA2
The Transient Radio Sky	Use fast radio bursts to uncover the missing "normal" matter in the universe.	Fast radio bursts as unique probes of fundamental cosmological parameters and intergalactic magnetic fields.
	Study feedback from the most energetic cosmic explosions and the disruption of 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).



The Cradle of Life: Understanding planet formation





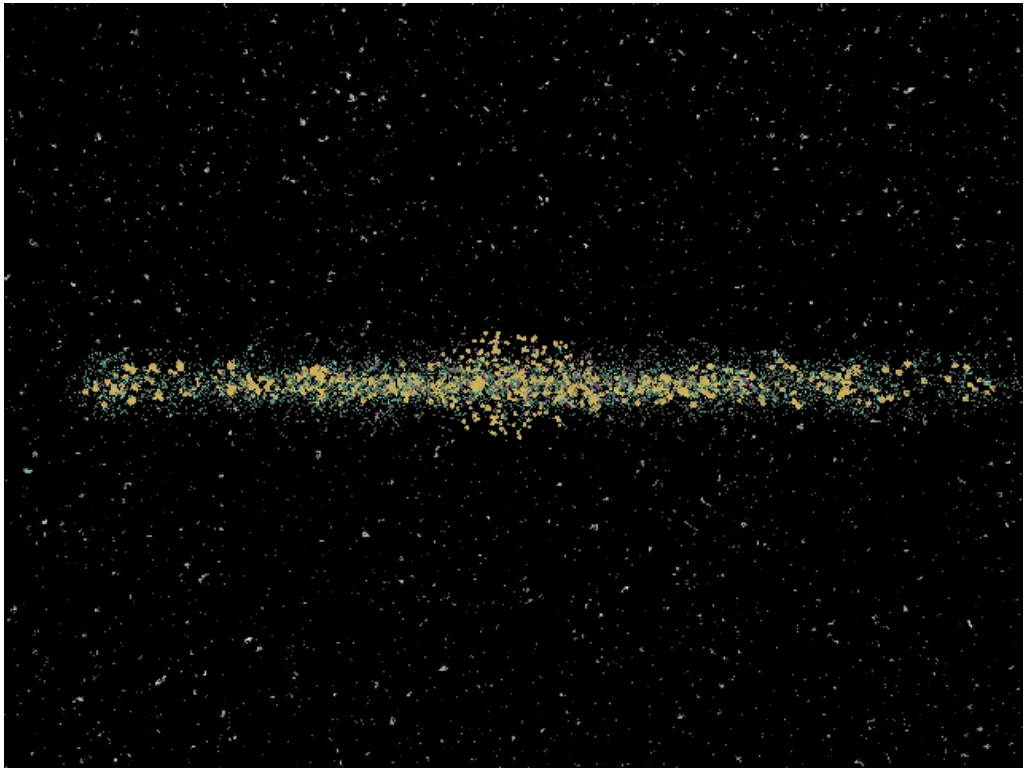


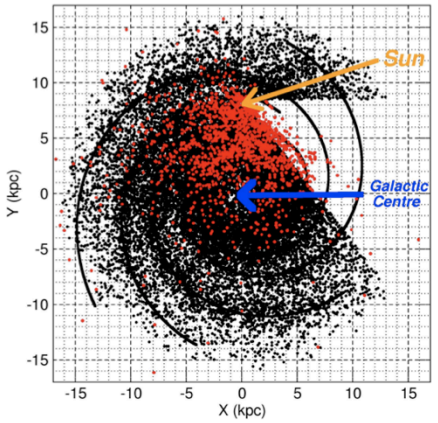
(Hasegawa & Pudritz 2012)

- Measuring grain growth through planetesimal phase
- Resolving proto-planetary disks at 100 pc (SKA1) or 300 pc (SKA2) inside the snow/ice line, sub-AU scales with SKA2

Finding all the pulsars in the Milky Way…

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

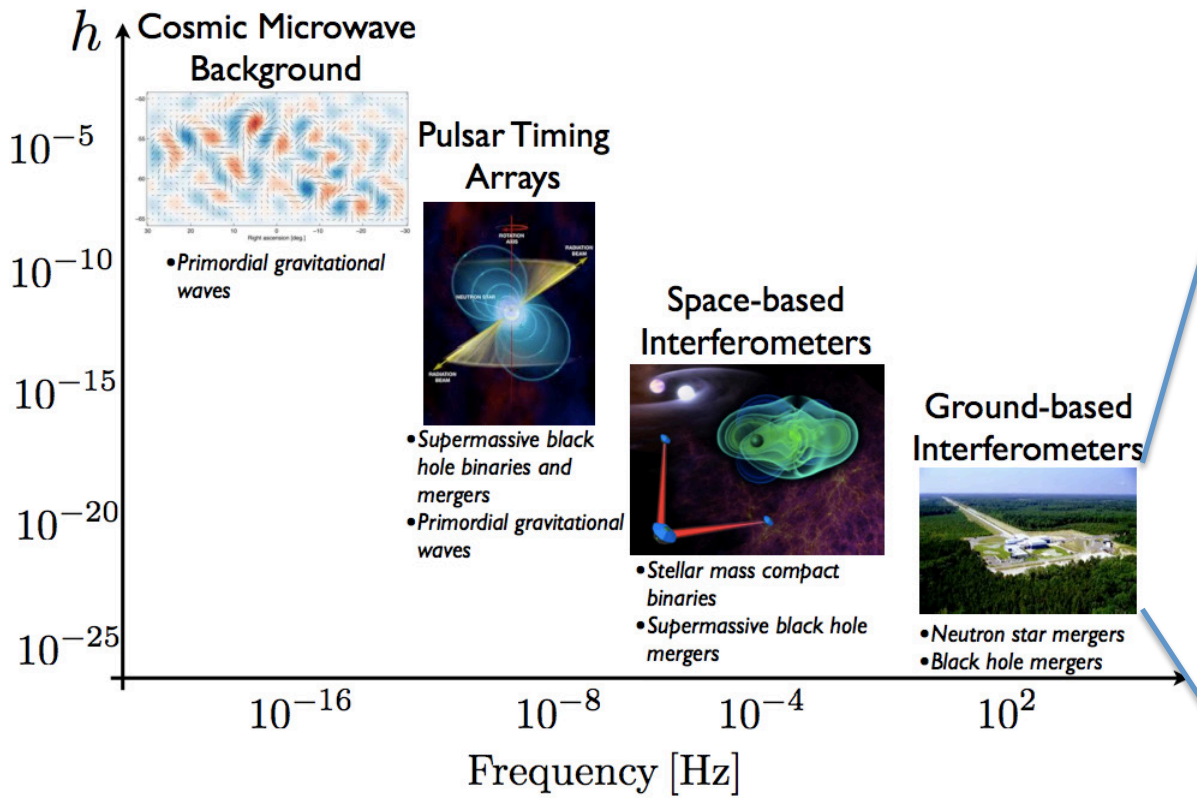


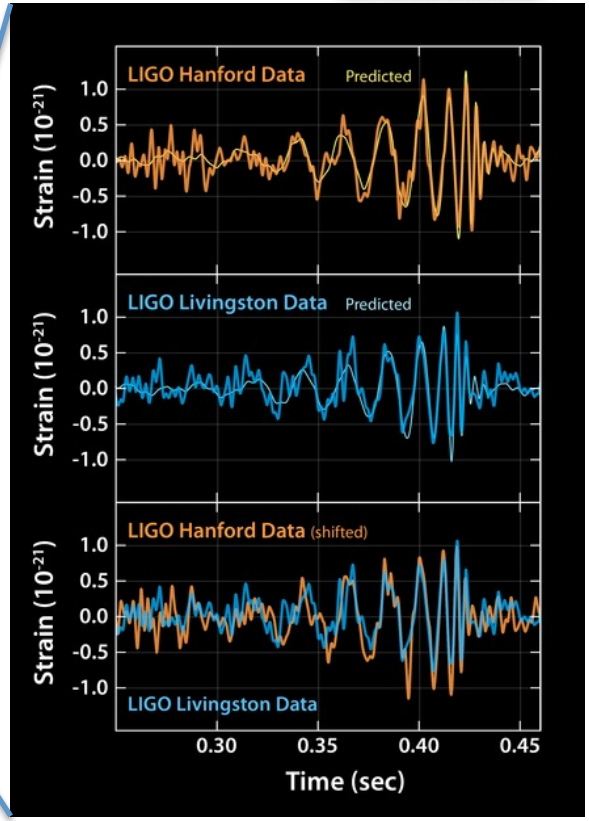


- ~40,000 normal pulsars
- ~2,000 millisecond psrs
- ~100 relativistic binaries
- first pulsars in Galactic Centre
- first extragalactic pulsars

- Timing precision is expected to increase by factor ~100: nHz Grav. Waves
- Rare and exotic pulsars and binary systems: including PSR-BH systems!
- Testing cosmic censorship and no-hair theorem
- **Current estimates are ~50% of population with SKA1, 100% with SKA2**

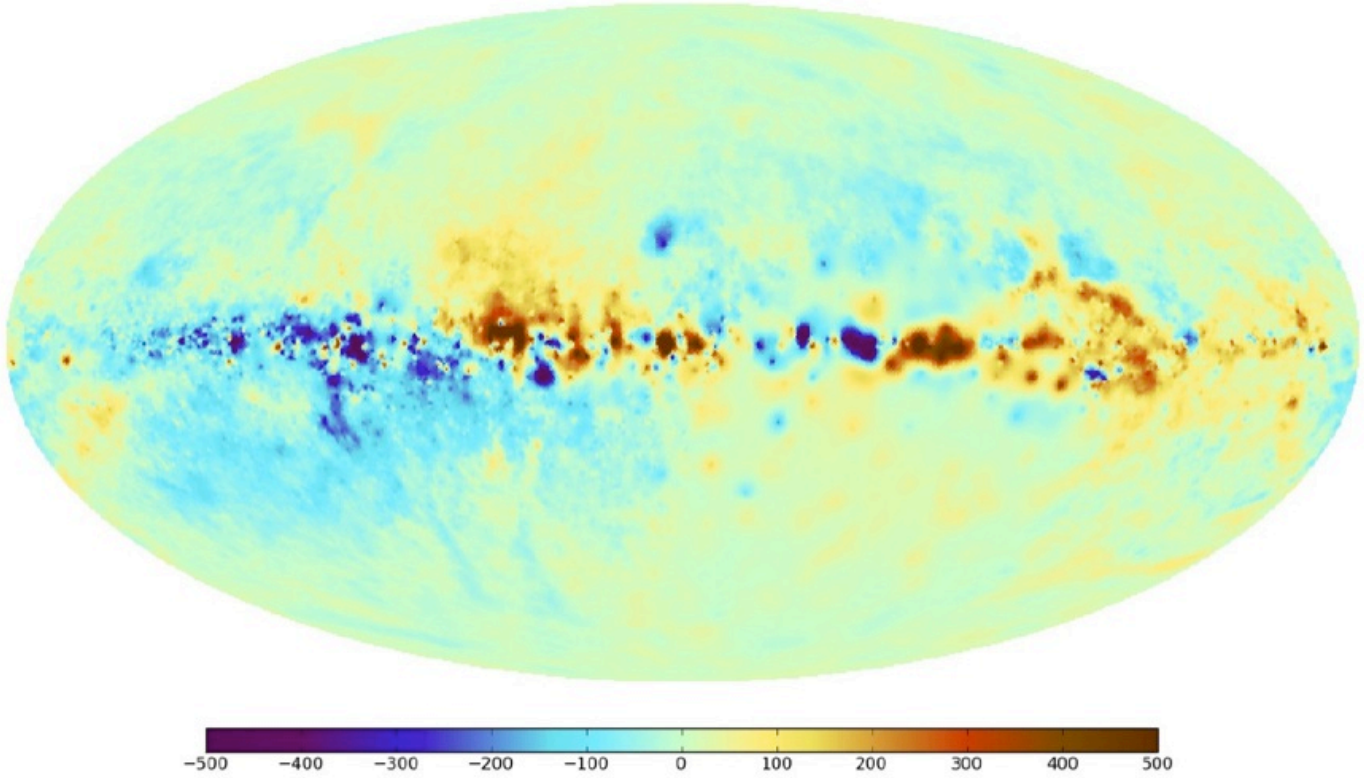
Finding all the pulsars in the Milky Way…





- Timing precision is expected to increase by factor ~100: nHz Grav. Waves
- Rare and exotic pulsars and binary systems: including PSR-BH systems!
- Testing cosmic censorship and no-hair theorem
- **Current estimates are ~50% of population with SKA1, 100% with SKA2**

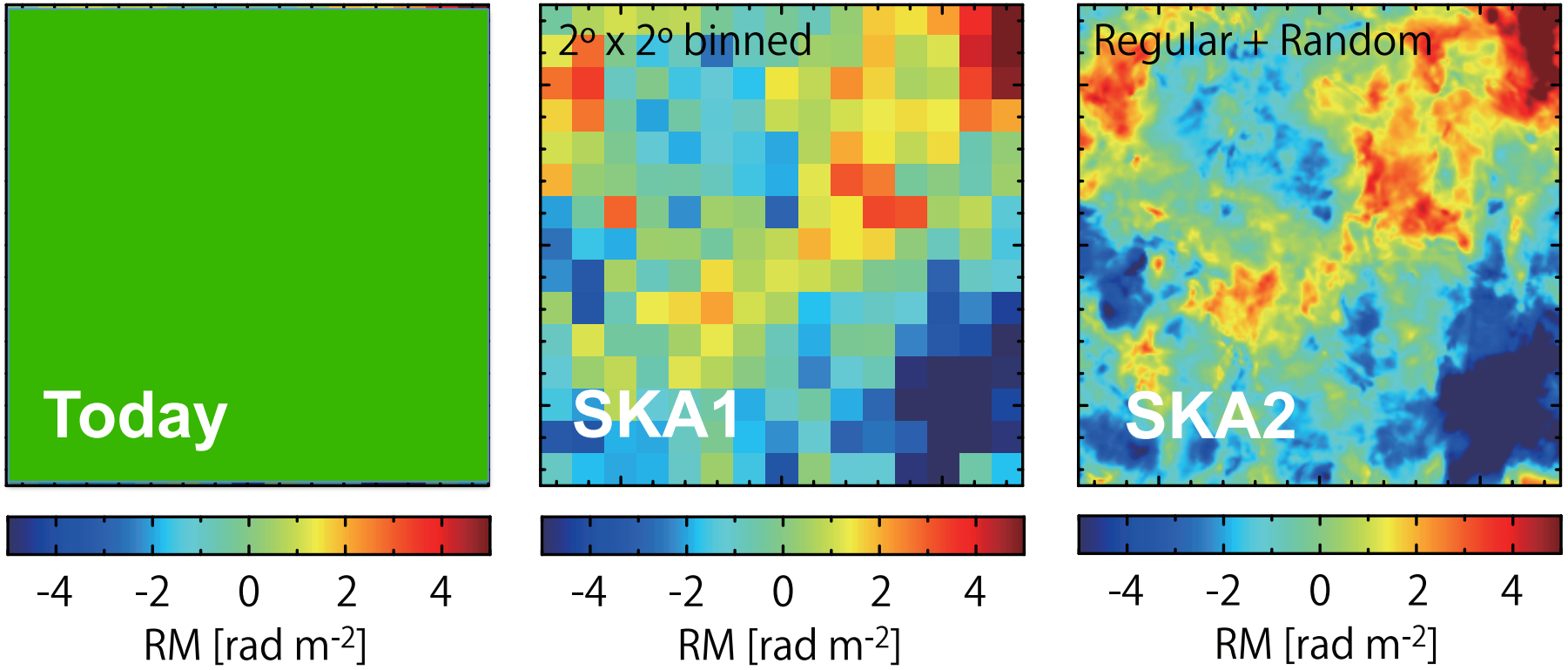
Headline Magnetism Science



Oppermann et al. (2012) ~40,000 extra-galactic RMs over 4π sr

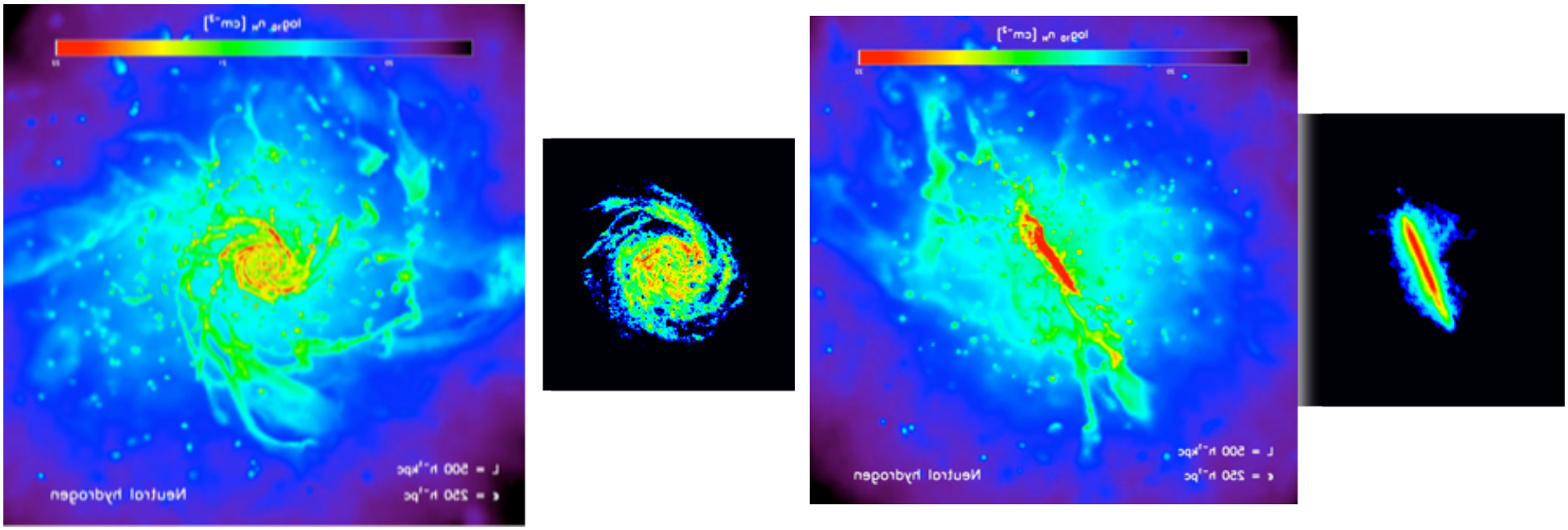
- 3D magnetic tomography of the Galaxy and distant universe; from current 1 RM deg^{-2}, SKA1: 300 deg^{-2} to SKA2: 5000 deg^{-2}

Headline Magnetism Science



- 3D magnetic tomography of the Galaxy and distant universe; from current 1 RM deg^{-2}, SKA1: 300 deg^{-2} to SKA2: 5000 deg^{-2}

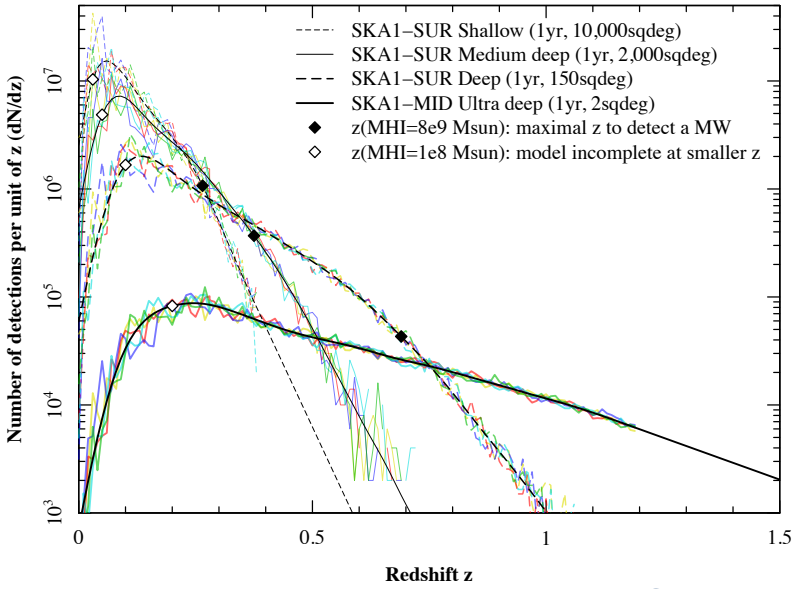
Galaxy HI Evolution:
out to z ~ 1 with SKA1 and z ~ 5 with SKA2

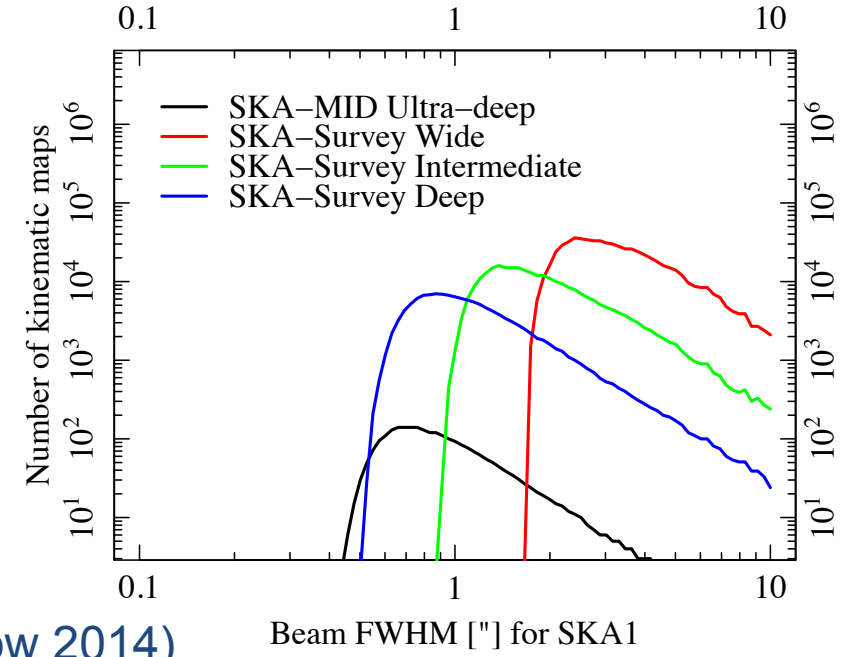


(Simulations: Schaye et al. 2010, Images: Oosterloo 2014)

- Understanding galaxy assembly and the baryon cycle
  - Determine the impact of galaxy environments
  - Probe gas inflow and removal, diffuse gas $N_{HI} < 10^{17}$ cm^{-2}
  - Measure angular momentum build-up

Galaxy HI Evolution: out to z ~ 1 with SKA1 and z ~ 5 with SKA2



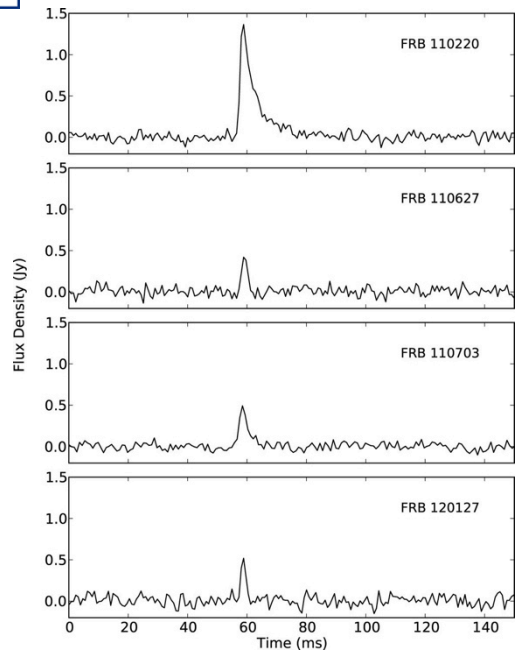


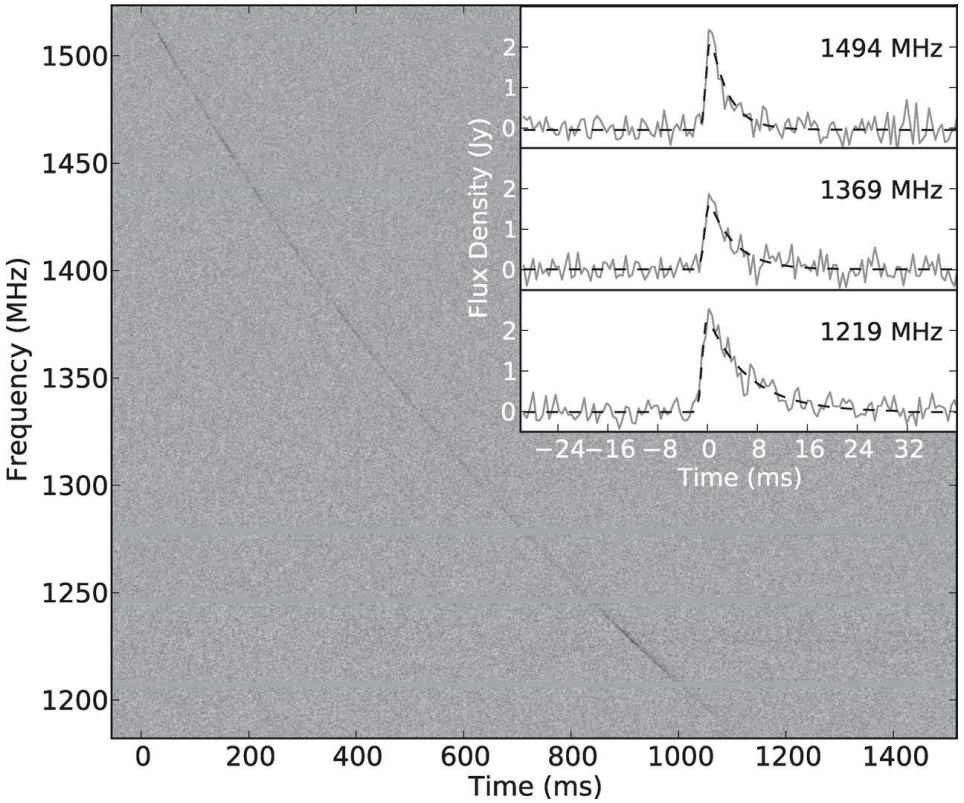
(Obreschkow 2014)

- Understanding galaxy assembly and the baryon cycle
  - Determine the impact of galaxy environments
  - Probe gas inflow and removal, diffuse gas $N_{HI} < 10^{17}$ cm^{-2}
  - Measure angular momentum build-up

The Transient radio sky

A Population of Fast Radio Bursts at Cosmological Distances
D. Thornton *et al.*
Science **341**, 53 (2013);
DOI: 10.1126/science.1236789





- Perhaps 10 – 15 celestial “FRB” events now detected (after first “Lorimer” burst):
  S = 0.5 – 2 Jy, Δt = 1 – 6 msec, DM = 500 – 2000 cm^{-3} pc
- Estimated event rate: $3x10^3$ sky^{-1} day^{-1}
- Unknown origin, likely at cosmological distances (Keane et al 2016)

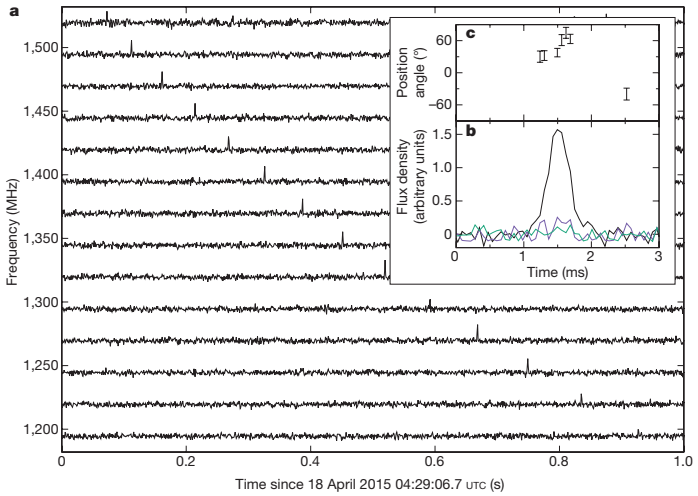
The Transient radio sky

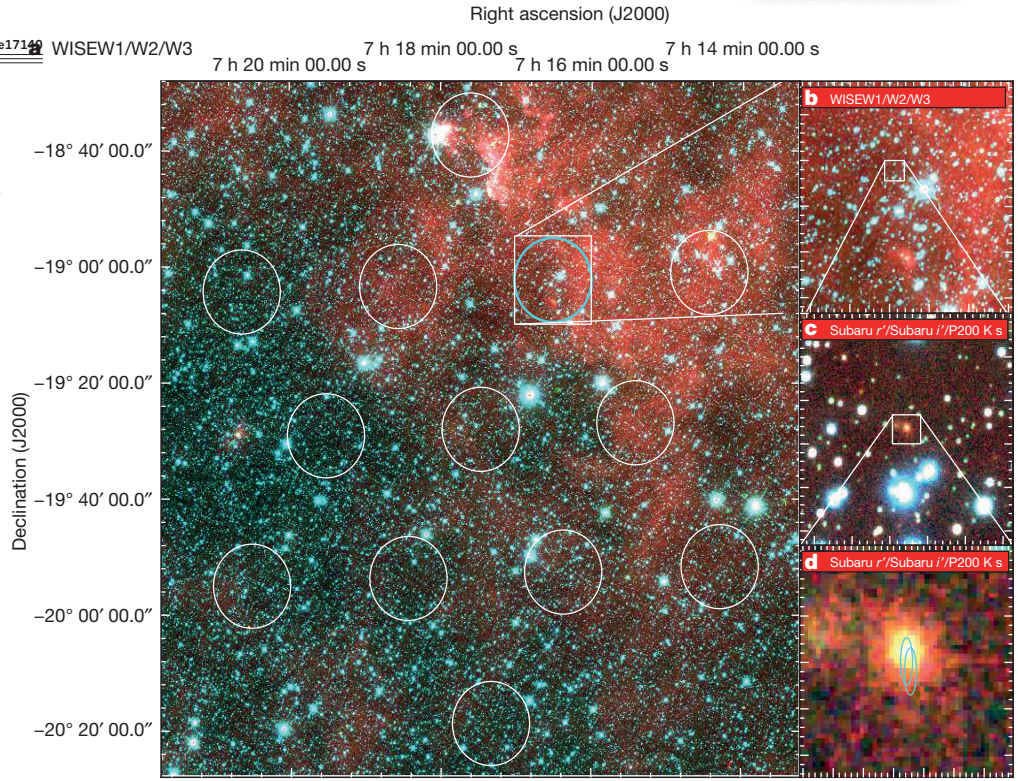
LETTER

doi:10.1038/nature17168

The host galaxy of a fast radio burst

E. F. Keane[1,2,3], S. Johnston[4], S. Bhandari[2,3], E. Barr[2], N. D. R. Bhat[3,5], M. Burgay[6], M. Caleb[2,3,7], C. Flynn[2,3], A. Jameson[2,3], M. Kramer[8,9], E. Petroff[2,3,4], A. Possenti[6], W. van Straten[2], M. Bailes[2,3], S. Burke-Spolaor[10], R. P. Eatough[8], B. W. Stappers[9], T. Totani[11], M. Honma[12,13], H. Furusawa[12], T. Hattori[14], T. Morokuma[15,16], Y. Niino[12], H. Sugai[16], T. Terai[14], N. Tominaga[16,17], S. Yamasaki[11], N. Yasuda[16], R. Allen[2], J. Cooke[2,3], J. Jencson[18], M. M. Kasliwal[18], D. L. Kaplan[19], S. J. Tingay[3,5], A. Williams[5], R. Wayth[3,5], P. Chandra[20], D. Perrodin[6], M. Berezina[8], M. Mickaliger[9] & C. Bassa[21]





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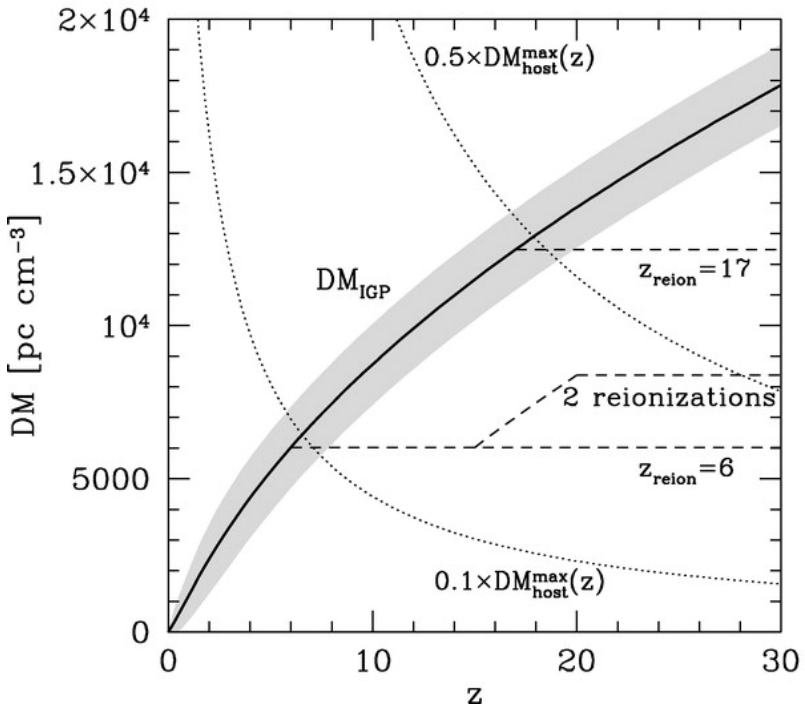
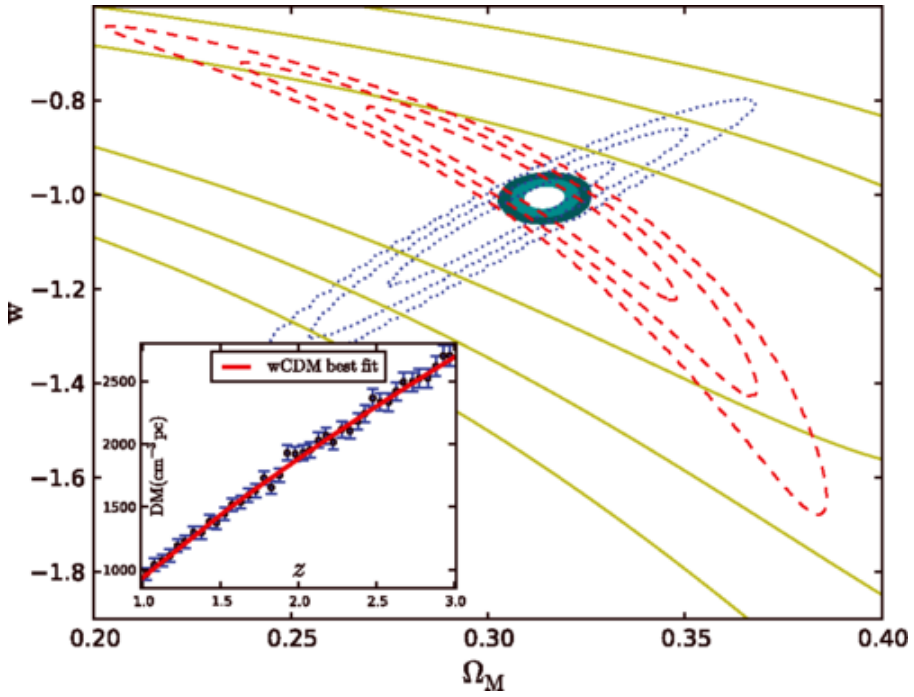
Transients headline science: Fast Radio Bursts as a cosmological probe



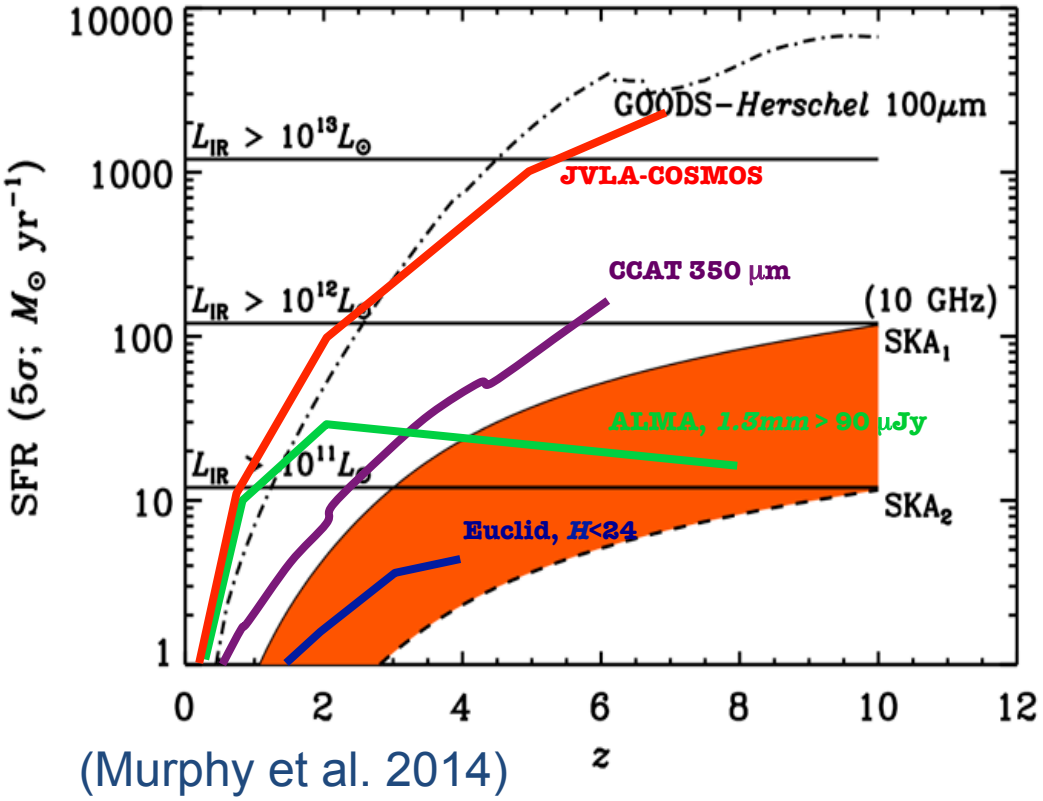
(Ioka 2003)



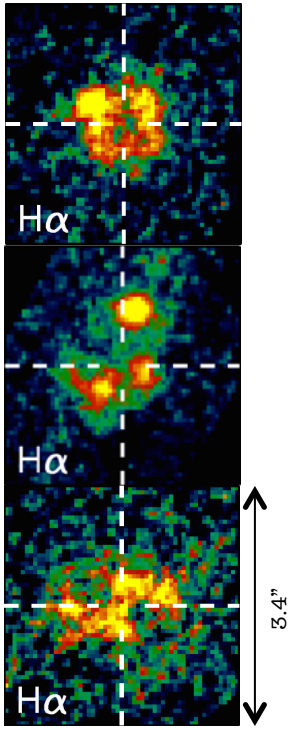
(Zhou et al. 2014)

- Prospects for fundamental contributions to cosmology with large samples (~1000) of spectroscopically identified FRBs out to z ~ 2 with SKA1 and z ~ 5 with SKA2

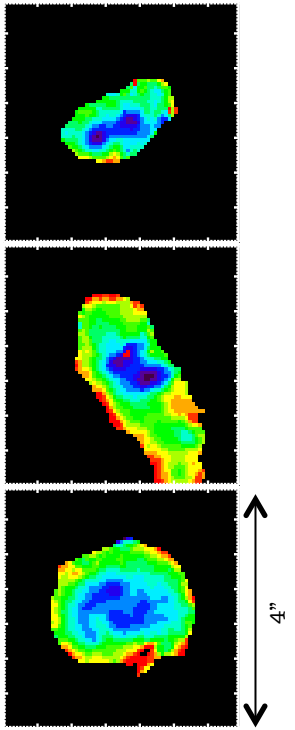
Galaxy Evolution Studies in the Radio Continuum: Understanding the Star Formation History of the Universe



(Murphy et al. 2014)



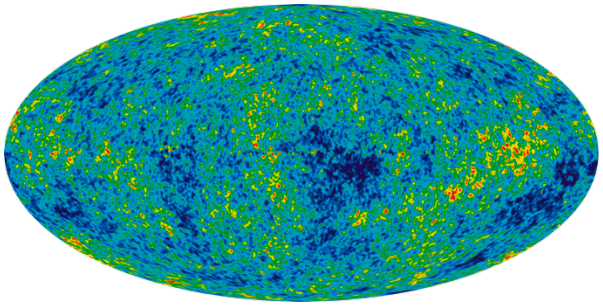
Wuyts et al 2013, **z~1**
Hα–based SFR-maps

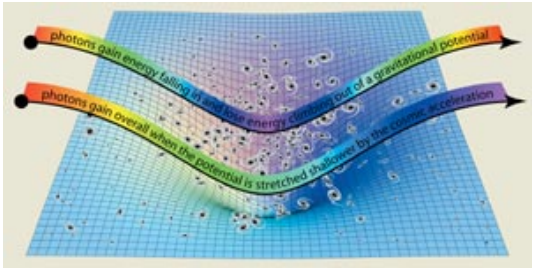


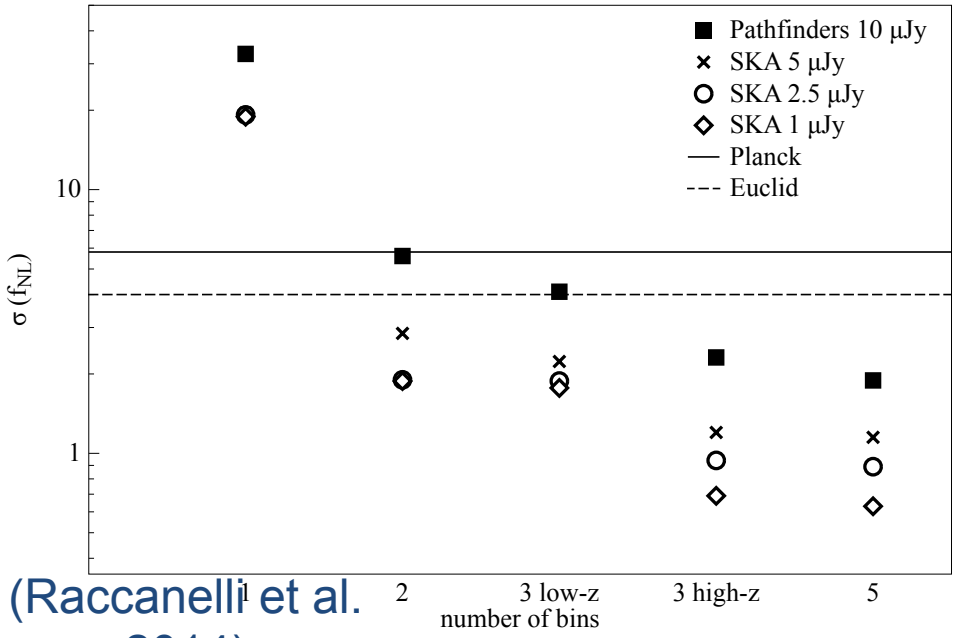
Cibinel et al 2014, **z~2**
UV-based SFR-maps

- Unmatched sensitivity to star formation rates (10 $M_\odot$/yr) out to z ~ 4 with SKA1 and z ~ 10 with SKA2
- Resolved (sub-kpc) imaging of star forming disks out to z ~ 1 with SKA1 and z ~ 6 with SKA2

Cosmology with SKA: Integrated Sachs-Wolfe effect



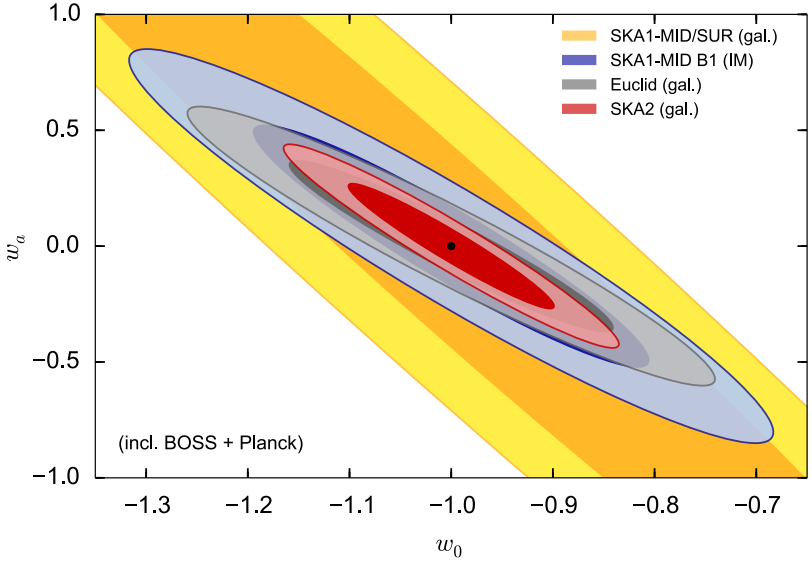




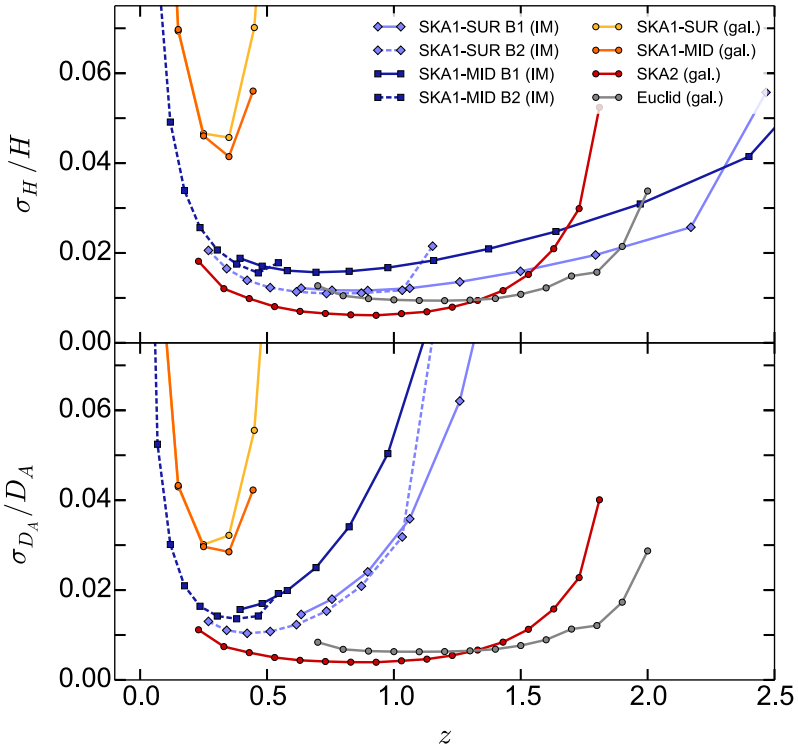
(Raccanelli et al. 2014)

- 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

Cosmology with SKA: Baryon Acoustic Oscillations

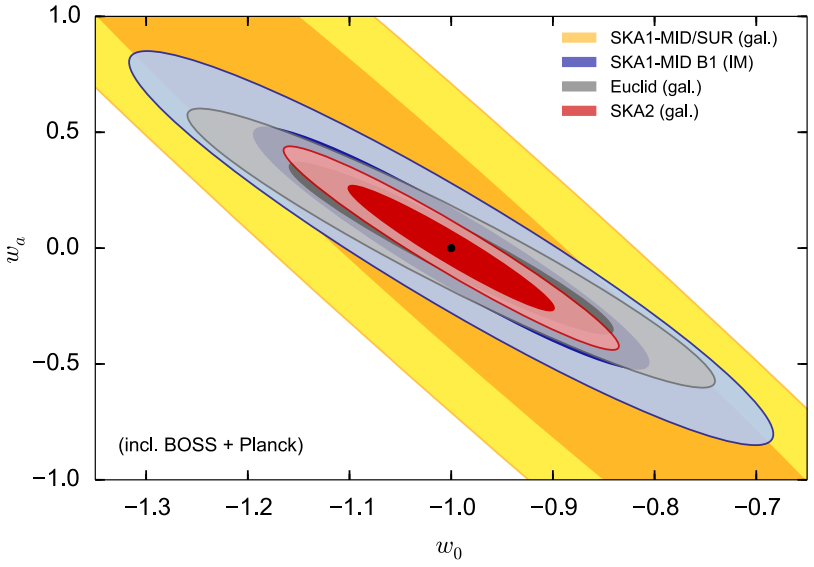


(Bull et al 2014)

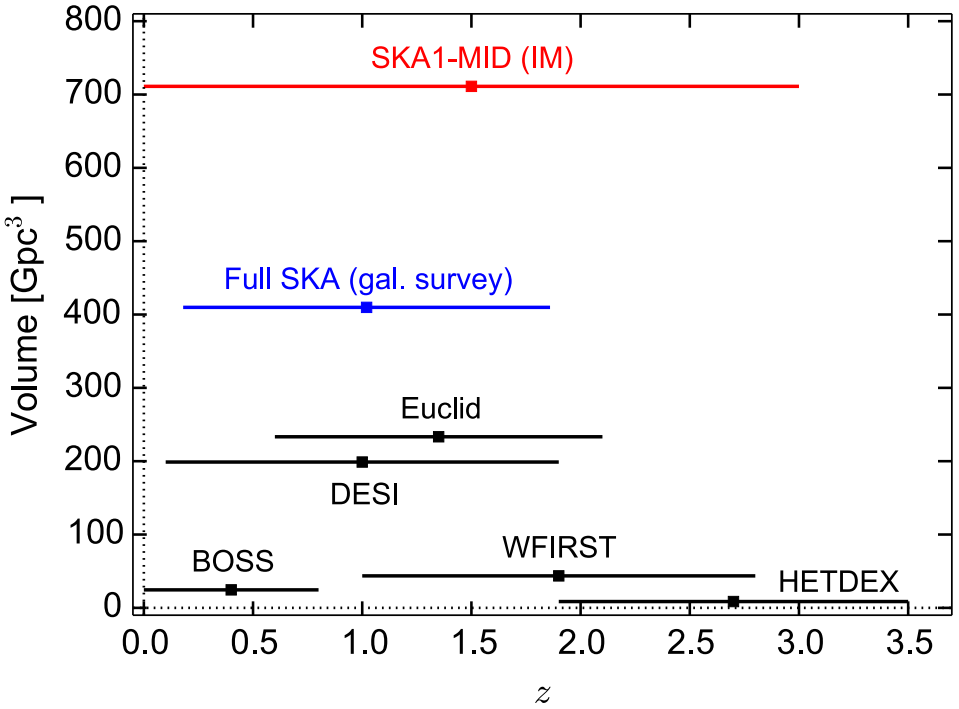


- Constraining Dark Energy models with redshift-resolved BAO measurements
  - Discrete detection is complementary with SKA1, cutting edge with SKA2
  - Intensity mapping is higher risk but world-class, even with SKA1

Cosmology with SKA: Baryon Acoustic Oscillations



(Bull et al 2014)



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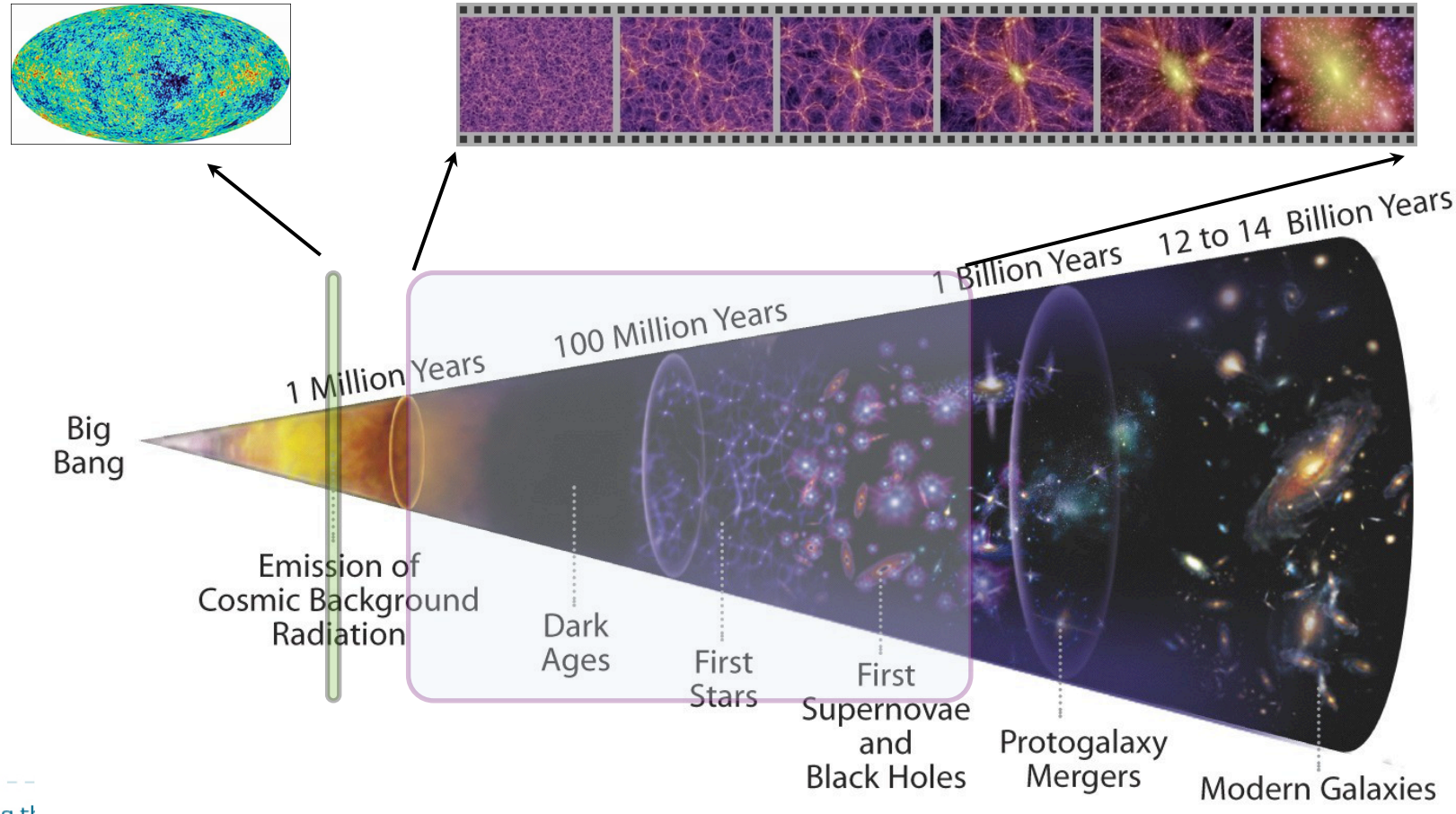
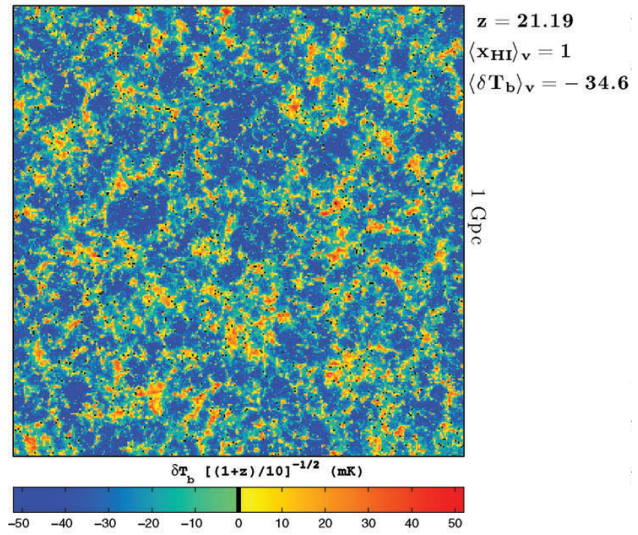
HI surveys of the EoR, Cosmic-Dawn & Dark Ages

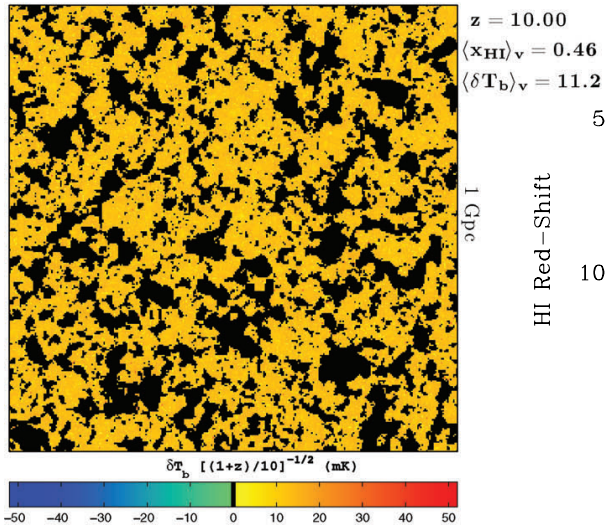
CMB displays a single moment of the Universe. Its initial conditions at ~400,000 yrs

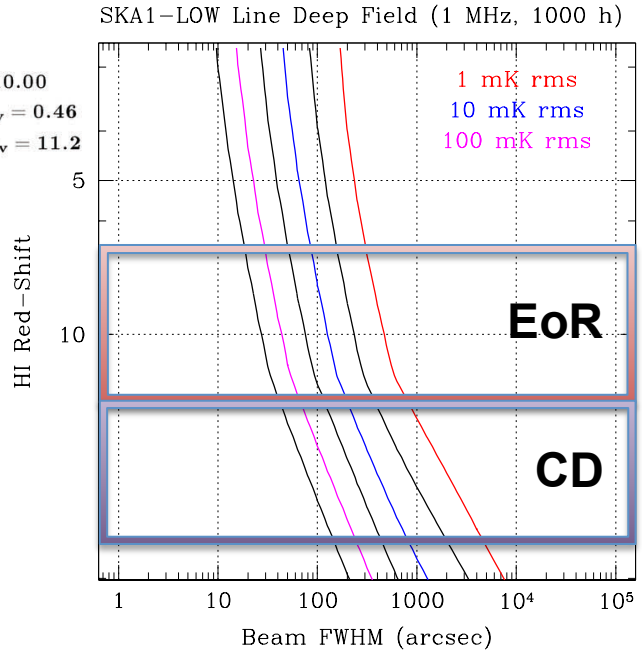
HI emission from the Dark Ages, Cosmic Dawn & EoR traces an evolving "movie" of baryonic and DM structure formation at $t_{univ}<10^9$ years.



SKA1 surveys of the EoR (& Cosmic-Dawn)







(Mesinger et al 2011)

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

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